ANALYSIS OF 1202 ORTHOPANTOGRAMS TO EVALUATE THE POTENTIAL OF FORENSIC AGE DETERMINATION BASED ON THIRD MOLAR DEVELOPMENTAL STAGES

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Abstract: A total of 1202 orthopantograms of young dental patients were analyzed to assess the correlation of third molar root development with chronological age. The investigated patients were treated at a university dental clinic on an outpatient basis, included a variety of demographic characteristics (600 males and 602 females, 28% of other than central European background), and were 15-24 years old when the radiographs were obtained. Radiographs in which more than one third molar were either missing due to agenesis or extraction, or not evaluable because of deep destruction or marked tilting, were not included in the analysis. Our findings show that the growth patterns of third molars, based on seven defined stages of root development, did correlate with chronological age; age estimation when applied to a specific individual would involve a margin of error of ± 2-4 years. There were no significant differences between the left and right jaw segments, but the stage of root development was generally more advanced in the upper than in the lower third molars. Root development was also more advanced among boys than among girls of the same age. There were no apparent differences in growth patterns based on national/ethnic background. While only 2.5% of 1.8-year-olds revealed fully developed third molars in all four quadrants, this percentage leaped to 38.4% among the 21-year-olds. To summarize, while the developmental stage of third molars is not per se a highly useful indicator of chronological age in juveniles and young adults, it is nevertheless a valuable supplementary parameter given the scarcity of other available age indicators.

Key words: Developmental stages of third molars; chronological age

INTRODUCTION

The importance of determining the chronological age of juvenile offenders in the context of criminal proceedings has significantly increased in many European countries over the past few decades. This development reflects the growing influx of migrants into industrialized countries, which naturally also involves greater numbers of foreign nationals for whom no clear documentation of age is available. Interest in determining the age of living persons, notably of adolescents for whom birth records are available, is not a recent phenomenon but has a long history. In ancient Rome, for instance, adolescents were considered fit for military service as soon as their second molars had fully emerged [16].

An exemplary historical precedence of the use of tooth development as an indicator for chronological age has been handed down from 19th-century England [14]. English legislation at the time stipulated that children under seven were not punishable for any crimes they committed. Since modern birth registers did not yet exist, it was often difficult to establish the age of children and thus protect them from punishment [17]. Age estimation was also important, however, in enforcing child labor regulations. In 1833, a strict ban was imposed on employing children under nine in spinning mills, and the working hours for up to 13-year-olds were limited to nine hours a day. As the only legal standard as to how the age of these children was to be determined, it was required that they should have the normal body strength and stature of a 9-year-old [13].

Today a number of criteria are available to determine the age of individuals [3, 9, 12, 18], usually involving the expertise of radiologists, odontologists or anthropologists [1]. If all medico-legal and ethical requirements are met, certain methods of age estimation are considered useful and are recommended [19]. The German Association of Forensic Odonto-Stomatology recommends physical examination including anthropometric measurements (body height and weight, physique); evaluation of sexual maturity and any age-related developmental abnormalities; X-ray assessment of the left hand; as well as dental examination including dental status and radiography, usually in the form of orthopantography.

Age estimation based on tooth development mainly relies on patterns of tooth emergence and regularities in the transition from deciduous to permanent dentition. "Tooth age" has been postulated as an important criterion of physical matur-
ity, as tooth development tends to be independent of environmental factors or systemic disease [16]. Helpful parameters in age estimation include mineralization processes of the crowns and roots of permanent teeth, anthropometric data in conjunction with tabulated values, as well as the development of secondary sexual characteristics and of the apophyseal/apophyseal joints. However, all of these growth processes will slow down over time, so that the parameters will become ever less accurate until they reach their definitive dimensions. Roughly speaking, in individuals who are past 25 all attempts at age estimation are doomed to failure [1].

In Germany there is a growing need for age estimation in juvenile offenders, the relevant age limits for criminal prosecution under German law being 14, 16, 18 and 21 years. §19 of the German Penal Code stipulates that individuals under 14 have no criminal responsibility. From that point on, two age categories are defined for juvenile offenders: those who, at the time of the offense, were 14 but not yet 18, and those who, at the time of the offense, were 18 but not yet 21 (§120 JGG). The provisions of juvenile criminal law are applicable if an individual who is between 14 and 18 years old commits an offense that is punishable under general regulations such as the German Penal Code or the Narcotics Act, or if an offender in the age range of 18–21, according to an overall personality assessment, had not passed the ethical and intellectual stage of the 14–18 range at the time of the offense, or if the offense, by the circumstances or motives involved, was specifically juvenile in nature (§105 JGG).

MATERIALS AND METHODS

A total of 1202 orthopantograms (OPGs) of young male (n = 600) and female (n = 602) patients treated at a university dental clinic (Clinic and Polyclinic for Dental, Oral and Jaw Pathologies at Johannes Gutenberg University, Mainz, Germany) on an outpatient basis were analyzed for the study. All patients were 15–24 years old when the OPG was made. Patient data included in the analysis were name, sex, date of birth, date of OPG, and nationality. The age of the patients was calculated from the date of OPG and the date of birth. The nationality was derived preferably from the OPG documentation or, wherever this was reasonable, from the name of the patient.

The radiographs were obtained using either a Siemens Orthophos 3 (208/230 V, max. 9 A) or a Siemens Orthophos CD (90 kV, 12 mA) system. OPGs in whom more than one third molar were agenic or had been extracted were excluded. In addition, the third molars had to be positioned perpendicularly to the X-ray direction, i.e. teeth that were tilted in oral or vestibular direction were excluded.

The radiographs meeting these criteria were evaluated for the developmental progress of third molars based on a system by Kullman et al. [10] in which third molar root development is subdivided into seven stages. Teeth that were not adequately evaluable due to deep destruction or marked tilting were assigned stage "0". Kullman et al. originally developed this staging system for mandibular third molars but, for the purpose of the present study, we also used it for maxillary third molars. The seven stages are:

- Stage 1 or Ri-R 1/4
  - Early root development; < 1/4 of expected definitive root length
- Stage 2 or R1/4-R1/2
  - 1/4 to 2/4 of expected definitive root length
- Stage 3 or R1/2-R3/4
  - > 1/4 but < 3/4 of expected definitive root length
- Stage 4 or R3/4-Rc
  - > 3/4 but < 4/4 of expected definitive root length
- Stage 5 or Rc-Aci
  - Expected definitive root length reached, apical constriction yet to start
- Stage 6 or Ac-Aci
  - Apical constriction ongoing
- Stage 7 or Ac
  - Apex is closed, root development is complete

STATISTICAL ANALYSIS

Statistical data analysis was performed using SPSS for Windows (V 8.0) in collaboration with the Institute of Medical Statistics and Documentation at Johannes Gutenberg University, Mainz, Germany. Data were represented both as mean and as median values. The mean values calculated from the quantitative assessments were given with 95% confidence intervals.

RESULTS

In the present study, a total of 1202 OPGs of dental patients (male: n = 600, female: n = 602) were evaluated. They had been treated at a university clinic on an outpatient basis and were 15–24 years old when OPGs were made. Wherever the indications of national and/or ethnic background were clear, patients were grouped into central Europeans, southern Europeans and Turks. The remaining cases (e.g. Asians, Africans or South Americans) were summarized in a separate group (Table 1). Turks as a separate category was a natural choice since people of Turkish background currently account for around 11% of the German population, so that a high percentage of patients at our clinic would also fall in this category.

Third molar growth patterns are illustrated in Figures 4–8 in the form of box and whisker plots for each quadrant. It is apparent that root development correlated with age in all third molars. The root mineralization process typically starts at age 15–16 (Fig. 1) and then continuously unfolds (Fig. 2) until the apex is completely closed and the root fully developed, which typically occurs at age 20–21 (Fig. 3).
Table 1. Sex and national/ethnic distribution

<table>
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<tr>
<th></th>
<th>males</th>
<th></th>
<th>females</th>
<th></th>
<th>total</th>
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<tr>
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<td>%</td>
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<tr>
<td>Central European</td>
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<td>33,7</td>
<td>460</td>
<td>38,3</td>
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<tr>
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<td>5,2</td>
<td>142</td>
<td>11,8</td>
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<tr>
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<td>37</td>
<td>3,1</td>
<td>75</td>
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Fig. 1. OPG of a 15.6-year-old girl of central European background.

Fig. 2. OPG of a 18.2-year-old girl of Turkish background.

Fig. 3. OPG of a 21-year-old woman of central European background.
Based on upper right third molars (Fig. 4) the mean age at stage R1 was 16.3 years, with lower and upper 95% confidence limits of 15.9 and 16.7 years, respectively. The youngest age at which mineralization was observed was 15.0 years, which is not a relevant finding as 15 years was the lower age limit for inclusion in the study. The oldest age at which mineralization was observed was 19.4 years, so that the overall span for stage R1 was 4.4 years. The mean age at stage R1/4 was 16.4 years, the 95% confidence interval being 16.3–17.1 years. The mean age at stage R3/4 was 17.4 years, the 95% confidence interval being 17.1–17.8 years, the total age range being 15.2–20.3 years (= span of 5.1 years). The definitive root length (stage Rc) was reached at a mean age of 18.0 years, the 95% confidence interval being 17.5–18.5 years, the total age range being 15.2–22.0 (= span of 6.8 years). The mean age at stage Aci was 18.4 years, the 95% confidence interval being 18.2–19.0 years. Apex closure was completed at a mean age of 21.0 years, the 95% confidence interval being 18.2–19.0 years, the total age range being 15.0–24.0 years (= span of 9 years).

The leap between growth stages Aci and Ac is due to the fact that the values for Ac are increasingly difficult to estimate, as there is no radiographic pattern to accurately define the point at which root development has been completed.

Comparative analysis of right and left third molars did not reveal any statistically significant differences, i.e. the roots developed symmetrically. Nor do the box and whisker plots in Figures 4–8 reveal any marked differences between teeth 18 and 28 or between teeth 38 and 48.

The sex-specific distribution of growth patterns is outlined in Figure 8. Third molar roots started to develop earlier in life among the boys than among the girls: root mineralization of the maxil-
Fig. 6. Developmental stages of the left lower third molar (38) plotted against chronological age (in years) based on a sample of outpatients including both sexes.

Fig. 7. Developmental stages of the right lower third molar (48) plotted against chronological age (in years) based on a sample of outpatients including both sexes.

Fig. 8. Developmental stages of the right upper third molar (18) plotted against chronological age and sex distribution.
Fig. 6. Developmental stages of the left lower third molar (38) plotted against chronological age (in years) based on a sample of outpatients including both sexes.

Fig. 7. Developmental stages of the right lower third molar (48) plotted against chronological age (in years) based on a sample of outpatients including both sexes.

Fig. 8. Developmental stages of the right upper third molar (18) plotted against chronological age and sex distribution.
lary third molars started 0.8 years earlier, the subsequent developmental stages started up to 1.4 years (R4/4) earlier. In overall terms, the boys were ahead of the girls by a mean of 0.7 years.

The population-specific distribution of growth patterns is outlined in figure 9 based on tooth 18. Ages are given as median (MED) and mean (MN) values to facilitate comparison of data. The number of investigated patients (N) and standard deviations (SD) are also shown. For the sake of completeness, age distributions for the southern European and Turkish subsets as well as for the subset including "other" national/ethnic backgrounds are given as well, even though the case numbers involved are too small to generalize these data.

Adequate sample sizes for all groups are only available for stage Ac. It emerges that the root development of tooth 18 was first completed among the Turkish population (mean age: 20.6 years ± 2.1 SD), followed by "Other" (mean age: 20.7 years ± 2.0 SD). By comparison, the central European subpopulation (mean age: 20.9 years ± 1.9 SD) reached stage Ac 0.3 years later than the Turkish population and 0.2 years later than "Other". All in all, the age differences were so small that the root development of tooth 18 was completed around age 21, at a standard deviation of around 2 years, in all analyzed groups.

**DISCUSSION**

The purpose of the present study was to explore ways to identify the age limits for criminal prosecution between 14 and 21 years based on radiographic assessment of third molar root development by analyzing a large number of orthopantomograms on record for non-adult dental patients. In addition to breaking these patients up into male or female, they were also investigated against their national/ethnic backgrounds, considering that a relatively high proportion of the German population are not of central European descent. This was true of 28% of analyzed patients, a percentage that reflects the demographics of 15-24-year-olds in the German population in a representative manner.

Our results demonstrate a pattern of third molar root development that is less uniform than in other teeth. Root calcification in the lower third molars started at a mean age of 16.0 years, which is well within the ranges given by other authors. By comparison, Johanson [8] reported a mean age at onset of third molar root development of 15.8 years, Levesque et al. [11] of 12.6-16.8 years, Nortje [17] of 16.5 years, and Thorson and Hägg [20] of 14.0 years. All those authors used different techniques of estimation and almost invariably confined their observations to the lower third molars.

According to our own findings, stage R1/4, where around one-fourth of the root of the third molar is calcified, was reached at a mean age of 16.9 years, compared to a mean of 17.5 years given by Nortje [17], 15.4 years by Thorson and Hägg [20], and 16.4 years by Loitz [1992]. Stage R1/2, where the root is mineralized over half of its expected definitive length, was reached at a mean age of 17.2 years, compared to 17.2 years given by Harris and Nortje [7], 17.0 years by Thorson and Hägg [20], 16.9 years by Kullmann et al. [10], and 17.7 year by Mincer et al. [15].

Stage R3/4, where the root of the third molar is calcified over three-fourth of its expected definitive length, was reached at a mean age of 17.7 years, compared to 17.8 years given by Nortje [17], 17.8 years by Harris and Nortje [7] (based on two-thirds of the root), 17.9 years by Loitz [13], and 17.3 years by Kullman et al. [10].

Stage Rc, where the root has reached its definitive length while apical constriction has not yet begun, was reached at a mean age of 18.2 years,
compared to 18.5 years according to both Engström [2] and Harris and Nortje [7], while Loitz [13] gave a slightly different mean age of 19.7 years.

Stage Rc, where the root has reached its definitive length and apical constriction is ongoing, was reached at a mean age of 19.7 years, compared to 18.5 years according to Nortje [17], 19.2 years according to Kullmann et al. [12] and 21.3 years according to Loitz [13].

Stage Ac, where the apex is closed and root development thus completed, was reached at a mean age of 21.3 years, compared to 19.0 years according to both Engström [2] and Nortje [17], 19.2 years according to both Harris and Nortje [7] and Thorson and Hägg [20], 23.2 years according to Loitz [13], and 20.2 years according to Mincer et al. [15]. The reason for the especially great variability of reported ages for this specific stage is that this result heavily depends on the age category of the analyzed population.

Our comparative analysis of maxillary versus mandibular third molars showed synchronous developmental stages in 68% of cases. In 16% the maxillary third molars were one stage ahead, and in 6% they were two stages ahead. The stage of root calcification (stage R) was often observed in the mandibular third molars before their maxillary counterparts entered this stage. In all subsequent stages, the third molar roots generally developed at a faster pace in the maxilla than in the mandible. These results indicate a longer phase of growth for mandibular than for maxillary third molars.

Regarding the sex distribution, our results indicate a delayed development of both the upper and lower third molars in girls as compared to boys by a mean of 0.7 years.

Whether the various national/ethnic groups included in our study were characterized by different growth patterns could not be clearly answered, since the southern European, Turkish and “Other” subsets were too small to address this question. A sufficient number of cases were only available for stage Ac (marking the final stage of third molar root development), according to which the root development in tooth 18 was completed first among the Turkish population (mean age: 20.6 years) and last among the southern European population (21.1 years), the central European and “Other” populations taking an intermediate position. The fact that the process of third molar development was completed within half a year in all patients suggests that there are no significant developmental differences between the national/demographic groups investigated.

Most previous investigators either did not investigate different population groups, or they neglected any observed differences in growth patterns because their sample sizes were too small. Garn et al. [4], Harris et al. [6] and Gravelly [5] reported noticeable differences in third molar development between black and white Americans. Both groups found that the third molars of black Americans developed and emerged faster than those of white Americans. Mincer et al. [15] did not confirm these results but attributed their failure to observe differences in third molar growth between black and white Americans to the small sample size.

Both our own results and the findings reported by other authors point to a number of factors to be considered because they may otherwise distort the results of age estimation based on radiographic assessment of third molar development. As the single most important of these factors, third molars show a less uniform growth pattern than all other teeth. The growth variability in the various stages of third molar development considerably adds to the difficulty of age estimation. Mincer et al. [15] suggested that the estimated age would always be within 4.8 years of the actual age after applying the 95% confidence interval. In our own study, the estimated and actual ages were not more than 1.1 years apart after applying the 95% confidence interval, while the overall variability including all outliers was substantially higher. Therefore the presented approach to age estimation can only perform in a satisfactory manner when additional parameters are used. In order to obtain more accurate results, the upper and lower third molars should be assessed on a separate basis, and the sex factor should also be included.

To summarize, age estimation in non-adults based on third molar development is only a realistic option when it is embedded in a broader context. Obviously enough, however, the main reason why this parameter is used after all lies in the scarcity of alternative methods to determine the age of individuals in this age category.

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Received: July 2, 2001 / Accepted: September 6, 2001

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