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ORIGINAL ARTICLE

Developmental stages of permanent canines, premolars, and 2nd molars in 244 Danish children

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Abstract

Objective. The purpose of this study was to establish reference values for maturity of permanent canines, premolars, and permanent 2nd molars in Danish children, and to focus on differences between the right and left sides, males and females, and the maxilla and mandible. ***Material and Methods.*** Panoramic radiographs from 106 males (8–14 years) and 137 females (7 years 2 months to 13 years 8 months) were analyzed, along with the maturity of the canines, premolars, and 2nd molars in each radiograph. Each tooth was categorized according to Haavikko's crown and root morphology. Inter-observer reliability was performed. For statistical analysis, Bowker's test was used for symmetry evaluation and comparison of maturity in the maxilla and mandible. The association between stage and age was presented by cumulative distributions. The Wilcoxon rank sum test was used for evaluating differences between genders. ***Results.*** Differences in maturity between the left and right sides were non-significant. A significant difference in dental maturity was observed between males and females, except for the maxillary 2nd premolar. Females matured earlier than males. The mandibular canines matured significantly earlier than the maxillary canines in females. No significant differences between the jaws were observed in the maturation of the premolars and 2nd molars. ***Conclusion.*** These reference values for dental maturity can be useful in orthodontic treatment planning and as a reference for odontological forensic age determination.

Key Words: *Age estimation, Danish population, dental maturity, forensic medicine, orthodontics*

Introduction

Several methods have been developed for radiographic evaluation of dental maturity before, during, and after tooth eruption.

In 1960, Nolla evaluated longitudinal material from the Child Developmental Laboratories of the University of Michigan School. The material consisted of intra-oral and extra-oral radiographs of 25 males and 25 females aged between 2.1 and 23.3 years [1]. Dental development was divided into 10 stages, i.e. from the first visible follicular clarification to root closure, with a corresponding numeric value from 1 to 10. The sum of these values was then converted into dental age. The teeth in both the maxilla and the mandible can be evaluated using this method, and dental age can be calculated for the maxilla, the mandible, or for the entire dentition.

In 1963, Moorrees [2] described the development in 14 stages of 10 permanent teeth in American material: 1 central and 1 lateral incisor in the maxilla and 8 teeth in the mandible. The same evaluation was made on longitudinal material of intra-oral and extra-oral radiographs [2]. Based on this study, and in order to evaluate deviations for each tooth, Moorrees created a diagram showing the time when each tooth passes to a new stage.

In 1970 and 1974, Haavikko [3,4] evaluated the entire dentition using panoramic radiographs of 1162 Finnish children aged between 2 and 21 years. Primarily, the evaluation was based on Moorrees' 14 stages. Later, Haavikko omitted two stages, and so the evaluation was based on 12 stages [4].

The median age was calculated for each stage in each tooth. Using these values, dental maturity can serve as an expression of dental age. In 1974, the method was modified such that dental maturity was calculated based on four teeth, i.e. 47, 46, 44, and 41, for children under the age of 10, and 47, 44, 13, and 43 for children over the age of 10 [4]. The chronological age can be determined from these calculations.

In 1973, using panoramic radiographs from 4756 French–Canadian children, Demirjian described the

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development of 7 teeth in the left side of the mandible, classified into 8 stages from A to H [5]. Each stage was assigned a maturity score (1–100) that was transformed into an estimated dental age. The calculations give the child's dental age. If chronological age is not known, this dental age can be used to estimate chronological age. The method was slightly modified in 1976, and a system was developed based on four teeth: 34, 35, 36, and 37 [6]. This method is inaccurate because it is difficult to evaluate the dental age in children with agenesis, but Demirjian recommended that the contralateral tooth corresponding to the missing tooth was used. If this tooth is absent, the estimated age for the actual tooth under normal conditions is calculated.

Demirjian's method is the most widely used for estimating dental age, and is recommended by forensic pathologists in connection with age determination. The method is also useful for determining age in adoption and immigration cases. Chaillet et al. [7] have tested Demirjian's method on a series of populations. New standard values have been calculated for these populations, and deviation between the evaluated children and the French–Canadian standard has been clarified as well. An international standard that can be used when ethnic origin is unknown has been developed based on a large corpus of material from eight countries [7].

Teivens & Mörnstad [8] suggested a third-degree polygon which, based on very small material, can calculate a standard curve for the dental development of a given population. This has also been performed on a Dutch population, and a logarithmic equation for calculating the standard curve for dental maturity was developed [9].

In the 1990s, several radiographic methods were developed which could express dental age based on the lengths of teeth. These methods require a digitizer and a computer program, however, and are therefore not commonly used [10–12].

As comparative evaluations show a difference in dental maturity in different populations [9,13], it cannot be assumed that the mean values developed in these different studies express the dental maturity in Danish children.

The purpose of this study was to develop a reference value for dental maturity based on radiographic morphological criteria in a Danish population of children and to document similarities/differences between: the right and the left side, males and females, and the maxilla and the mandible.

Material

Panoramic radiographs (244) from three rural municipalities were analyzed, i.e. 106 from males and 138 from females born between 1965 and 1969. No specific information on ethnicity was given. The ages of the males ranged from 8 years 0 months to 14 years 0 months, and of the females from 7 years 2 months to 13 years 8 months (Table I). The radiographs were taken in connection with systematic screening for orthodontic treatment or orthodontic treatment planning. The number of evaluated radiographs distributed in age groups is given in Table I.

Methods

The following teeth were analyzed on each radiograph: permanent canines, 1st and 2nd premolars, and 2nd permanent molars in all four quadrants. Each of these teeth was categorized morphologically according to Haavikko's method for both crown and root [4]. In the present study, the following stages were determined: Crc (crown formation completed); Ri (root formation initiated); R¼ (the root has obtained ¼ length); R½ (the root has obtained ½ length); R¾ (the root has obtained ¾ length); Rc (root formation completed); Ac (apex closed).

Table I. Number of evaluated radiographs distributed from males (M) and females (F) distributed in age groups.

	7 y		8 y		9 y		10 y		11 y		12 y		13 y		14 y	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0 m			2	2	1	2	2	2	3	2	2	2	2	2	1	
1 m			0	2	1	2	2	2	2	2	2	2	2	2		
2 m		1	0	1	1	2	2	2	2	2	2	2	2	2		
3 m			0	0	1	2	2	2	2	2	2	2	1	2		
4 m			0	1	2	2	2	2	3	2	1	2	1	1		
5 m		2	1	2	2	2	0	2	0	2	2	2	2	2		
6 m		2	1	2	2	2	1	2	3	2	2	2	2	1		
7 m		1	0	0	2	2	1	2	1	2	2	2	0	2		
8 m			1	2	2	2	2	2	2	1	2	2	1	2		
9 m		1	1	2	2	2	1	2	2	1	2	2	0			
10 m		1	1	2	2	2	2	2	2	2	2	2	1			
11 m		2	1	2	0	2	1	2	2	2	2	2	0			
Total		10	8	18	18	24	18	24	24	22	23	24	14	16	1	

Methodological errors

In order to analyze intra-observer reproducibility, 49 radiographs from the females with an even age distribution were re-evaluated after 90 days.

Statistics

The statistical analysis of dental maturity was carried out using the cumulative distribution of age in the developmental stages in four tooth categories stratified by stage. For tooth category, the left and right sides of the mandible and maxilla were compared using Bowker's test for symmetry. If no significant differences were demonstrated, the left and the right sides were combined, the highest developmental stage being chosen as the basic observation for each subject. The same test was used to compare the mandible and maxilla in all categories stratified by gender. The association between stage and age was presented by the cumulative distribution. The median age and a measure of dispersion defined as the difference between the 90th and 10th percentiles are shown. Tests for difference between genders for each category were performed using the Wilcoxon rank sum test on the developmental stage, in particular R½. *P*-values $<5\%$ were considered significant. Median age and dispersion were also estimated using a probit model on the cumulative frequencies with age log transformed. Model fits were assessed using the likelihood ratio statistics. Cohen's weighted Kappa statistics with 95% confidence interval were used to assess intra-observer and inter-observer variability. All calculations were performed using SAS (v. 9.1, SAS Institute, Cary, N.C., USA).

Results

There were 106 boys and 138 girls in the dataset, with a median age 11.3 years for males and 10.6 years for females. Comparison of the left and right sides showed that none were significant with all p-values >0.5. The left and right sides were therefore combined for further analysis.

Figures 1 and 2 show the cumulative distributions for each category stratified by gender. Table IIA gives the median ages at which the canines, 1st and 2nd premolars, and 2nd molars in each jaw reach the different maturity stages. The ages increase gradually depending on advancement in maturity stage, except for two stages in the 1st premolar. This inconsistency could be due to the size of the material. Table IIAA also indicates dispersion values, which are the difference between the 90th and 10th percentiles. It can be seen that females mature earlier than males and that testing R½ demonstrates a significant difference, except for the 2nd maxillary premolar (Table III). Table IIB gives the estimated median using the probit model. It was not possible to estimate the median age for developmental stage Crc because of the lack of data. In addition, some median ages are not shown because of too few data. The table also gives the dispersion as defined above. Goodness-of-fit tests demonstrated adequate fits of shown data.

A test for the difference between the mandible and the maxilla cannot demonstrate significance (all p-values >0.48) except for the canines in girls ($p=0.0003$) (Table IV). Table IV gives the distribution of canines for females. It can be seen that there is a significant fraction of females with a higher developmental stage in the mandible than in the maxilla. In males, the same analysis is not significant ($p=0.94$).

Methodological errors

In the analysis of methodological errors, an intra-observer accuracy of 0.78 (95% confidence interval: 0.72–0.84, Cohen's weighted Kappa) was seen between the first and second observations, most prominently in the last three stages. Inter-observer accuracy was 0.93 (95% confidence interval: 0.91–0.94 Cohen's weighted Kappa). Generally, maturity in the second registration was evaluated to be more advanced than in the first (Table V). A deviation of more than one stage was observed in eight observations.

Discussion

As the purpose of this study was to develop reference values for dental maturity in Danish children, i.e. children born and living in Denmark, it was important to make sure that the material used was representative of a Danish population. Even though the study is based on radiographs of children from three rural municipalities, the material is determined to be representative because a previous study of the dental eruption in Danish children [14] showed only minor and insignificant differences between the dental eruption in children from rural and city areas. Furthermore, the socio-economic differences in Denmark are very small [14]. In addition, the radiographs came from children born between 1965 and 1969, when the ethnic composition of the Danish population was much more uniform than it is today.

The material is not equal, as the radiographs of children in the age group 9–10 years were taken in connection with a systematic screening of all children for dental deviations, whereas the remaining radiographs were taken by indication in connection with screening for orthodontic treatment or orthodontic treatment planning.

Due to the age distribution of the material it was not possible to evaluate the maturity of the permanent incisors and the 1st molars. However, it was possible, with a few exceptions due to the quality of the

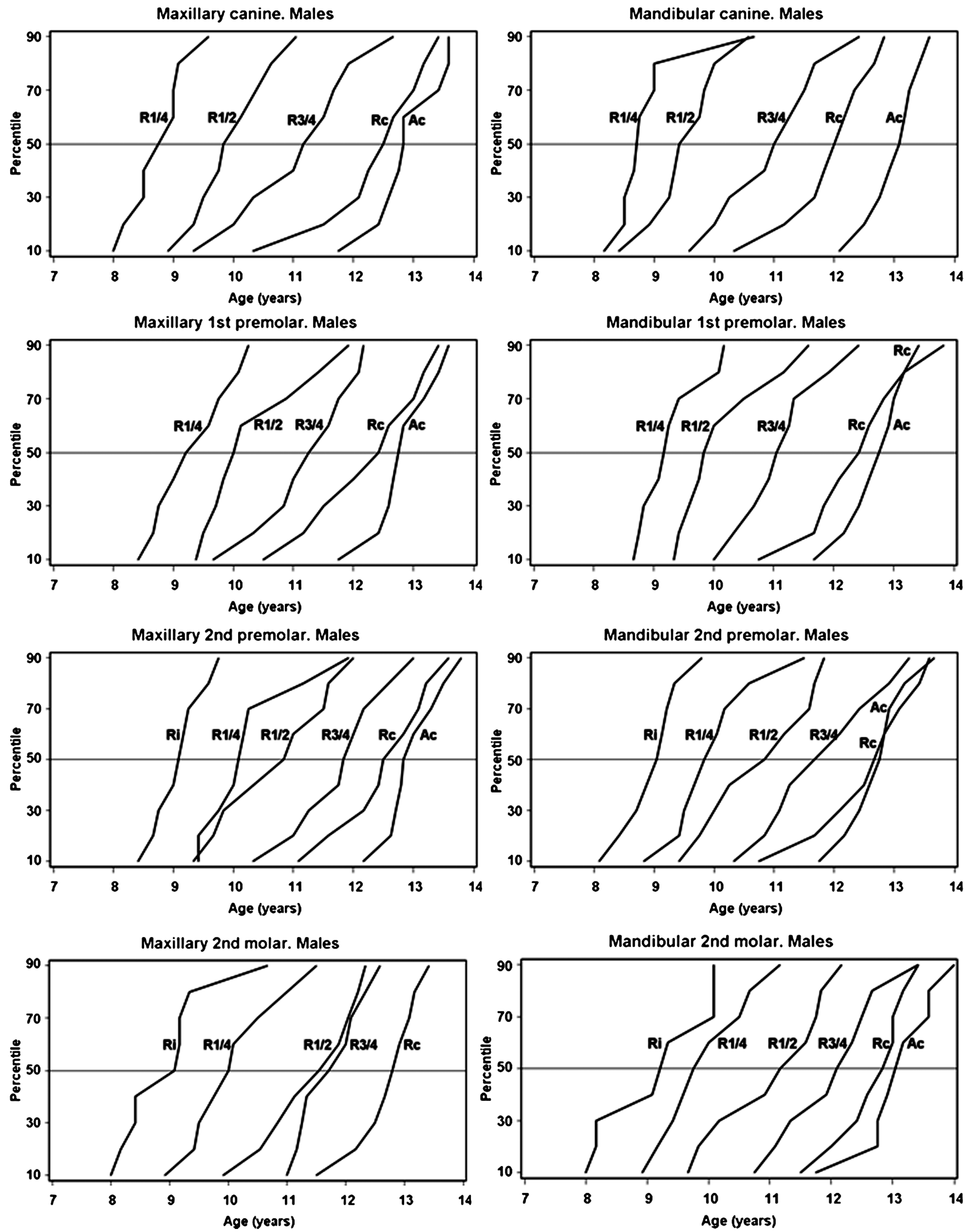

Figure 1. Cumulative frequency curves by age for different tooth formation stages in maxillary and mandibular canines, 1st and 2nd premolars, and 2nd molars in males. The curves are marked by stages. The stages are: Crc crown completed; Ri root formation initiated; R¼ root has obtained quarter length; R½ root has obtained half length; R$\frac{3}{4}$ root has obtained three–quarters length; Rc root formation completed; Ac apex closed.

radiographs, to evaluate the dental maturity of the root formation in the permanent canines, 1st and 2nd premolars, and 2nd molars.

The reasons for choosing Haavikko's method [4] rather than Demirjian's [5], Moorrees' [2], or Nolla's [1] methods were as follows. Haavikko's

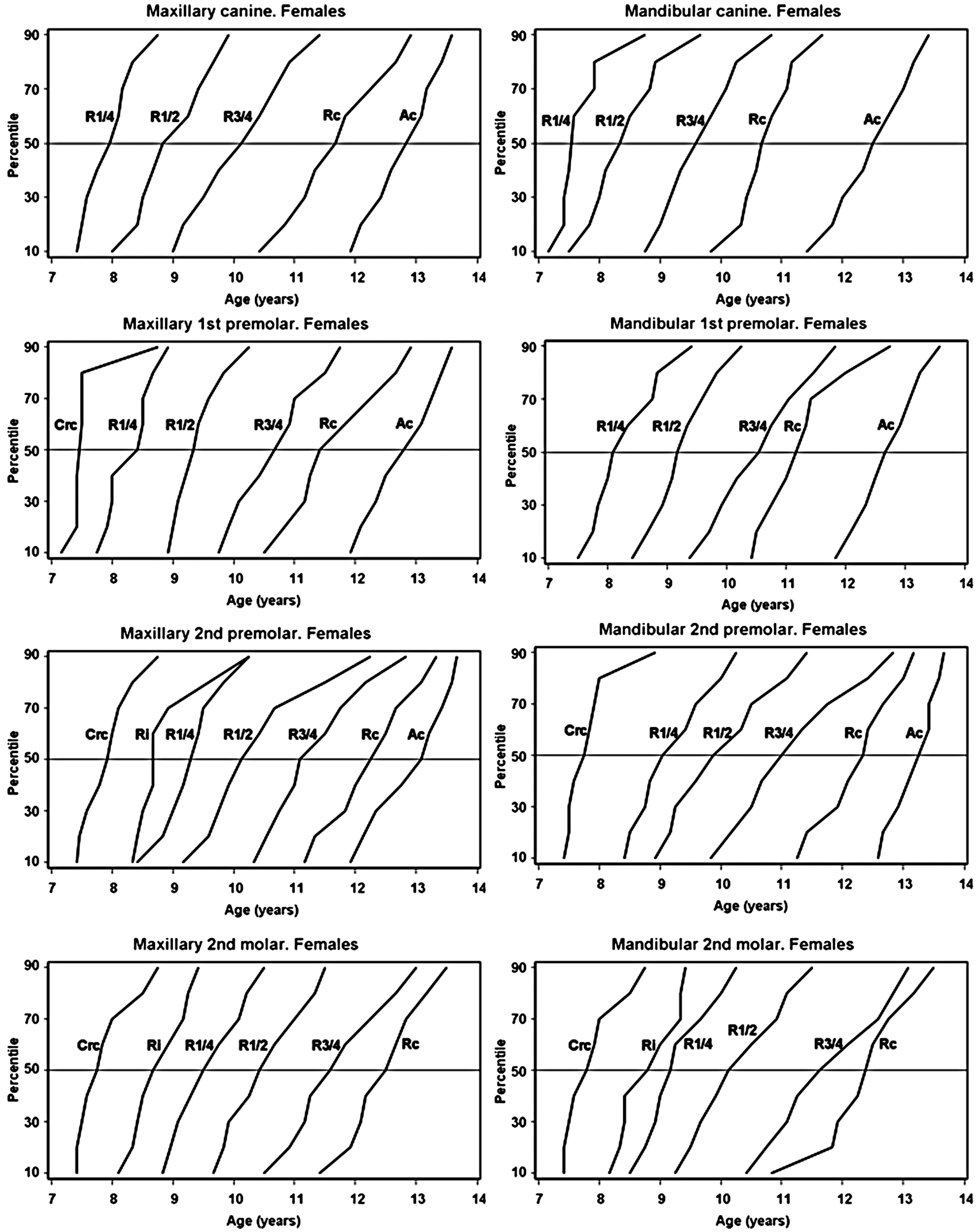

Figure 2. Cumulative frequency curves by age for different tooth formation stages in maxillary and mandibular canines, 1st and 2nd premolars, and 2nd molars in females. The curves are marked by stages. The stages are: Crc crown completed; Ri root formation initiated; R¼ root has obtained quarter length; R½ root has obtained half length; R¾; root has obtained three–quarters length; Rc root formation completed; Ac apex closed.

method was developed based on Finnish material as opposed to that of Moorrees and Nolla, who developed their methods based on North American material, and Demirjian's method, which was based on a French–Canadian population. Although all methods were based on Caucasian children, it must be assumed that the closest compatibility exists between the two Scandinavian groups of children.

Table IIA. The median ages in a Danish population at which the canines, 1st and 2nd premolars, and 2nd molars in each jaw reach the different maturity stages. Dispersion indicates the difference between the 90% and 10% percentiles. Numerals in parentheses indicate number of cases. Crc: Crown formation completed; Ri: Root formation has started; R¼: root has obtained ¼ length; R½: root has obtained ½ length; R¾: root has obtained ¾ length; Rc: root formation completed; Ac: Apex closed.

	Males Maxilla		Males Mandible		Females Maxilla		Females Mandible	
	Median	Dispersion	Median	Dispersion	Median	Dispersion	Median	Dispersion
Canine								
Crc								
Ri			9.1 (1)	0.0	7.5 (2)	0.1		
R¼	8.8 (7)	1.6	8.7 (6)	2.5	8.0 (12)	1.3	7.5 (6)	1.6
R½	9.8 (20)	2.1	9.4 (17)	2.2	8.8 (21)	1.9	8.3 (19)	2.2
R¾	11.2 (39)	3.3	11.0 (34)	2.8	10.1 (42)	2.4	9.6 (41)	2.1
Rc	12.5 (29)	3.1	12.0 (29)	2.5	11.7 (31)	2.5	10.7 (19)	1.8
Ac	12.8 (11)	1.8	13.1 (19)	1.5	12.8 (29)	1.7	12.5 (53)	2.0
1st premolar								
Crc	8.3 (2)	0.5	8.5 (1)	0.0	7.5 (6)	1.6	7.4 (3)	0.3
Ri	9.8 (2)	1.5	8.6 (2)	0.8	8.1 (2)	0.1	8.5 (2)	0.8
R¼	9.2 (12)	1.8	9.2 (11)	1.5	8.4 (17)	0.2	8.1 (16)	1.9
R½	10.0 (20)	2.5	9.8 (21)	2.3	9.3 (25)	0.3	9.2 (28)	1.8
R¾	11.3 (24)	2.5	11.0 (26)	2.4	10.7 (32)	2.0	10.5 (30)	2.5
Rc	12.4 (33)	2.9	12.4 (28)	2.7	11.4 (23)	2.4	11.2 (21)	2.3
Ac	12.8 (13)	1.8	12.8 (17)	2.2	12.8 (32)	1.7	12.7 (38)	1.8
2nd premolar								
Crc	8.3 (2)	0.5	8.5 (1)	0.0	7.9 (15)	1.3	7.8 (11)	1.5
Ri	9.1 (11)	1.3	9.0 (10)	1.7	8.7 (8)	1.9	8.2 (5)	0.9
R¼	10.1 (14)	2.5	9.8 (15)	2.7	9.3 (24)	1.8	9.0 (24)	1.8
R½	10.8 (26)	2.7	10.8 (21)	2.4	10.1 (22)	3.1	9.9 (22)	2.5
R¾	11.8 (18)	2.7	11.7 (29)	2.9	11.1 (25)	2.5	11.0 (35)	3.0
Rc	12.5 (25)	2.5	12.7 (19)	2.8	12.3 (27)	2.2	12.3 (29)	1.9
Ac	12.8 (10)	1.6	12.8 (11)	1.9	13.1 (15)	1.8	13.3 (11)	1.1
2nd molar								
Crc	8.9 (2)	0.3	8.5 (3)	0.3	7.8 (13)	1.3	7.8 (14)	1.3
Ri	9.1 (7)	2.7	9.2 (6)	2.1	8.7 (16)	1.3	8.8 (12)	1.2
R¼	10.0 (33)	2.6	9.8 (23)	2.3	9.5 (25)	1.7	9.2 (9)	1.8
R½	11.5 (20)	2.4	11.2 (22)	2.5	10.4 (21)	1.8	10.1 (26)	2.3
R¾	11.7 (12)	1.6	12.1 (28)	2.7	11.6 (27)	2.5	11.6 (36)	2.7
Rc	12.8 (26)	1.9	12.8 (17)	1.9	12.5 (29)	2.1	12.4 (26)	2.7
Ac	13.0 (4)	1.8	13.0 (6)	2.3	13.1 (3)	0.3	13.3 (5)	0.8

Panoramic radiographs were used by Haavikko, as was the case in the present study. Thus, the teeth in both the maxilla and the mandible were evaluated; Demirjian used panoramic radiographs, but evaluated only one side of the mandible. In orthodontics, it is essential to be able to evaluate the entire dentition in both the maxilla and the mandible as well as the individual teeth.

Because the results are presented as median ages for each stage in each tooth, it may be possible in future to predict the eruption time of a tooth. This is determined based on the existing information of the duration of time passing from one stage to the stage where the tooth erupts under normal conditions. In the present study, one problem concerning mean age for each stage was that maturity stage Ri for the 1st premolar in two cases (males, maxilla and females, mandible) was reached at a later age than maturity stage R¼. This biological inconsistency may be due to the limited size of the material and has to be considered when using Table IIA for comparison of dental maturity.

Furthermore, Haavikko's method is based on a mean value calculated by the operator and not on a value extrapolated from a curve. This makes it easier to consider dentitions with agenesis or dentitions with teeth that clearly deviate from the maturity of the rest of the dentition. The two methods used for estimation of median age (Table IIA and Table IIB) show reasonable concordance. In addition, no systematic differences could be shown. The sample size is the likely cause of the discrepancies. In a larger sample designed to estimate reference ages, the probit model may be the preferred method.

Difference between the right and left sides

This study showed no significant difference in dental maturity between the right and left sides, which is in accordance with most previous studies [1–3,5,15].

Gender differences

Haavikko's study showed that dental development in females is 0.6 years earlier than in males, and that

Table IIB. The median ages in a Danish population estimated using a probit model on accumulative frequencies.

	Males Maxilla		Males Mandible		Females Maxilla		Females Mandible	
	Median	Dispersion	Median	Dispersion	Median	Dispersion	Median	Dispersion
Canine								
Ri	–	–	–	–	–	–	–	–
R¼	–	–	–	–	–	–	–	–
R½	8.7	1.4	8.4	2.4	8.2	1.3	7.5	1.6
R¾	9.8	2.9	9.8	2.0	9.2	2.0	8.7	1.7
Rc	11.8	3.3	11.5	3.1	11.0	2.2	10.5	1.8
Ac	13.9	4.0	12.9	2.3	12.4	2.3	11.4	1.1
1st premolar								
Ri	–	–	–	–	7.6	1.3	–	–
R¼	–	–	–	–	7.7	1.4	7.2	2.0
R½	9.2	2.3	9.1	2.1	8.8	1.1	8.5	1.9
R¾	10.3	3.1	10.3	2.5	9.8	1.4	9.8	2.1
Rc	11.5	3.4	11.6	2.8	11.2	2.3	11.1	2.4
Ac	13.7	4.0	13.3	3.9	12.3	2.1	12.0	1.9
2nd premolar								
Ri	–	–	–	–	8.3	1.1	8.0	1.5
R¼	9.2	1.7	9.0	1.7	8.6	1.8	8.3	1.4
R½	9.8	3.0	9.8	2.6	9.7	1.8	9.4	2.3
R¾	11.2	2.6	10.9	2.9	10.7	2.4	10.4	2.5
Rc	12.1	2.9	12.4	3.6	11.8	2.8	11.9	2.8
Ac	13.8	3.4	14.2	5.1	13.3	3.2	13.4	2.0
2nd molar								
Ri	–	–	–	–	8.1	1.3	8.2	1.2
R¼	8.7	2.1	8.8	2.0	8.9	1.7	8.7	1.9
R½	10.7	2.2	10.2	2.4	9.9	2.1	9.6	1.9
R¾	11.7	2.5	11.3	2.6	10.9	2.0	10.7	2.3
Rc	12.2	2.4	12.9	3.7	12.1	2.9	12.5	3.9
Ac	–	–	14.5	4.0	–	–	13.8	1.8

Table III. Differences between median ages in years for Danish males and females at maturity stage R½ in the maxilla and mandible. A positive difference shows earlier maturity in females compared to males. *P*-values <0.05 indicate significance.

Tooth	No. of males	**No.** of females	Difference in age	*P*-value
Difference between boys and girls in the maxilla at stage R½				
Canine	20	21	+1.0	0.001
1st premolar	20	25	+0.7	0.001
2nd premolar	26	22	+0.7	0.373
2nd molar	20	21	+1.1	0.006
Difference between males and females in the mandible at stage R½				
Canine	17	19	+1.1	0.000
1st premolar	21	28	+0.7	0.003
2nd premolar	21	22	+1.0	0.033
2nd molar	22	26	+1.0	0.023

Table IV. Cross-tabulation, including percentage, of the mandibular and maxillary canine stages in 119 females in whom the maxillary and mandibular canine developmental stages could be registered. The table shows a lack of symmetry indicating that mandibular canines mature earlier than maxillary canines.

	Mandibular canine. Females					
	Crc	R¾	R½	R¾	Rc	Ac
Maxillary canine. Females						
RR½	2 (2.7%)	4 (3.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
R¼	0 (0%)	8 (6.7%)	11 (9.2%)	0 (0%)	0 (0%)	0 (0%)
R¾	0 (0%)	0 (0%)	10 (8.4%)	31 (26.0%)	0 (0%)	0 (0%)
Rc	0 (0%)	0 (0%)	0 (0%)	8 (6.7%)	11 (9.2%)	0 (0%)
Ac	0 (0%)	0 (0%)	0 (0%)	3 (2.5%)	2 (2.7%)	29 (24.3%)

Table V. The first and second observations, both performed by the first author, of dental maturity of canines, premolars and 2nd molars evaluated on 49 panoramic radiographs. Numerals in boldface type express agreement in the two observations. Numerals to the left of the bold numbers indicate a less progressed maturity registered in the second observation, and numbers to the right of the bold numbers indicate a more progressed maturity. Crc, Ri, R¼, R½, R¾, Rc and Ac express the maturity stages. The table shows that the determined stage of maturity tends to be more progressed in the second observation than in the first.

	2nd observation						
	Crc	Ri	R1/4	R1/2	R3/4	Rc	Ac
1st observation							
Ac						11	**79**
Rc					5	**131**	
R¾				9	**214**	21	
R½			1	**90**	13		
R¼	5		**64**	5			
Ri		**33**	2				
Crc	**55**		2				

there are corresponding gender differences in the time of eruption. Moorrees' study [2] showed gender differences in tooth formation: 0.5–0.9 years for premolars and, slightly higher, 1.1 years for canines. Nolla [1] found only small gender differences in a longitudinal study of 25 males and 25 females. The gender differences in this study are similar to those observed in Moorrees' study. In the present study, no difference in maturity for the maxillary 2nd premolar was registered between males and females. This might be influenced by the age span for the different maturity stages, which is long. There is therefore a great overlap between the stages for males and females.

In the present study, it is obvious that the age span for a maturity stage is wider for males than for females. This is also described by Leurs [9]. The greater variation in males than in females was also described by Darwin [16], who explained the variation as being an important factor in the evolution of the species.

In Europe, children mature earlier and grow faster today than previously, most likely due to improved nutrition and a higher standard of living. In examining whether there has been a change during the past 30 years in dental maturity in European males and females, Holtgrave [17] found that a small acceleration in dental development had taken place in very young males. The reason for this change is not known.

As the radiographic material in the present study originates from 1965–1969, it can be assumed that the dental maturity today is slightly different from the results in the present study. The original study by Haavikko [3,4] was based on material from about the same period.

It is suggested that the Danish reference values presented in this study are used in orthodontic treatment planning for children in Denmark and as a reference standard for forensic odontological age determination.

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