

*D. L. Anderson,<sup>1</sup> D.D.S., M.Sc., G. W. Thompson,<sup>1</sup> D.D.S., Ph.D., and F. Popovich,<sup>1</sup> D.D.S., M.Sc.*

## Age of Attainment of Mineralization Stages of the Permanent Dentition

---

All teeth share morphologically distinct stages of mineralization which can be identified radiographically [1-11]. Bilaterally symmetrical teeth attain each stage at a similar age [1,7,9-12]. Among individuals, the age at which each stage is attained varies, and the variability increases with age [13]. Males and females differ in the age at which their permanent teeth attain various stages of mineralization [2,8,9,11,14], but Nolla [9] has reported the degree of variability is similar in both sexes. The amount of sex differential varies among the teeth and is greatest for the mandibular canines [2,8,9,14].

The determination of physiological or chronological age is important in many fields of investigation. Chronological age estimation from tooth stages is applicable to studies of juveniles in regions of the world where birth records are poor or absent; in circumstances where the reported age is suspect; in amnesia patients; and for specimen in forensic investigations and anthropology. Of all body structures, the jaws and teeth are most frequently available for examination [15].

Because tooth mineralization stages are affected much less than bone mineralization stages by variation in nutritional [16] and endocrine [17] status, developing teeth provide a more accurate indication of chronological age than do developing bones [18]. Tooth mineralization stages are preferable to eruption ages of teeth because they are affected less by the local environment and can be measured over a considerably longer period [1,2,8-11].

Previous serial studies of the age of tooth mineralization did not include either all types of maxillary and mandibular teeth [1-3,8,15,19] or all stages of the third molars [1-3,8,9,11,15,19]; or else they included more than one group of children [8,19]. Other studies were cross-sectional [5,7,10,20], combined the sexes [5,7,10], and used few stages [5,7,20]. The present investigation of one serial group describes the mean ages of attainment and standard deviations of the stages of mineralization of the maxillary and mandibular teeth, including all stages of the third molars.

### Material and Methods

The mineralization stage of each tooth type of the maxilla and mandible was scored by one examiner, according to the method of Moorrees et al [8], from annual cephalograms beginning at age 3 in 121 boys and 111 girls of the serial experimental group of the Burlington Growth Centre. This sample [21] consists of Caucasian children of mostly

Received for publication 18 April 1975; accepted for publication 16 May 1975.

<sup>1</sup> Associate professor, associate dean and associate professor, and professor, respectively, Burlington Growth Centre, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.

Anglo-Saxon origin and was representative of the population of the town of Burlington, Canada.

When there was a one-stage change from one record to the next, it was calculated that the change had taken place halfway between the first and second records. The midpoint between the chronological ages of the first and second records was taken as the age of the first appearance of that particular tooth stage. When there was a two-stage change between records, the interval increment was taken as one third of the difference between the first and second records. In this way it was possible to derive a chronological age for the first appearance of two different stages for any tooth. The same method was used when there were several stage changes between records. The mean age and standard deviation for each available stage of mineralization of each of the 16 teeth was determined for each sex.

## Results

The mean ages and standard deviations at individual stages of mineralization of the maxillary and mandibular teeth of the males and females are presented in Tables 1 to 4.

Teeth with similar ages of mineralization in order from youngest age to oldest were, for the males, first molars and mandibular incisors, maxillary incisors, canines and premolars, second molars, and third molars; and for the females, incisors and first molars, canines and first premolars, second premolars, second molars, and third molars.

The sexes differed significantly in the ages of mineralization of most teeth [14]. The males were older at all stages of all teeth except for the late stages of formation of the third molars. Other than for the third molars, the sex difference in age increased with successive stages of mineralization. The greatest difference occurred at the mandibular canine and was progressively less for each tooth farther away from the canines.

The corresponding teeth of the maxilla and mandible attained each stage of mineralization at a similar sex-specific age.

In both sexes the variability in age of dental mineralization increased with successive stages for all teeth except the third molars. Variability was greatest for the third molars; and for these teeth the variability increased from stage 1 to 6 or 7, depending on the sex, decreased to stage 11 or 12, and then increased again at stages 13 and 14.

Variability was greater among the males than females for the incisors and canines at all stages. The sex differences in variability of age was greatest for the first premolars. For the second premolars, variability was greater among the females at stages 1 to 5, and greater among the males from stages 6 to 14. The sexes were similar in variability of age for the first molar stages 7 to 12, but variability was greater among males at stages 13 and 14. The sexes were similar for the second molars, but variability of age of the third molars' stages tended to be greater among the females.

The teeth arranged in order of amount of variability in age from most to least were, for the males, first premolars and third molars, second premolars and second molars, canines, incisors and first molars; and for the females, third molars, second molars, canines and premolars, incisors and first molars.

## Discussion

The data presented cover all ages from 3½ to 18 years and should be applicable to age determinations in Caucasians of this age range. The tables may be useful for estimations of age in other contemporary and ancient humans as well.

Although the mineralization stages of the teeth indicate physiologic development [5,12] more than chronological age, the dental mineralization stages are closely related to chronological age. Dental mineralization is a better measure of chronological age



TABLE 2—Age (years) of Attainment of Mineralization Stages of Teeth of the Male Mandible.

Stage	Incisors						Premolars						Molars									
	Central		Lateral		Canine		First		Second		First		Second		First		Second		Third			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
1									3.7	0.38									3.8	0.45	9.4	1.40
2									4.0	0.55									4.3	0.54	10.2	1.44
3									4.3	0.62									4.8	0.53	10.8	1.47
4											4.1	1.54	4.8	0.57	3.4	0.20			5.3	0.60	11.5	1.49
5			3.6	0.24	3.9	0.41	4.8	1.28	5.5	0.63	4.1	1.28	5.5	0.63	3.6	0.17			5.9	0.62	12.4	1.50
6	3.6	0.21	4.0	0.46	4.8	0.59	5.6	1.21	6.3	0.70	4.8	1.21	6.3	0.70	3.7	0.14			6.7	0.71	13.3	1.51
7	4.0	0.46	4.8	0.46	5.7	0.68	6.6	1.17	7.2	0.73	6.6	1.17	7.2	0.73	3.7	0.28			7.6	0.75	14.1	1.48
8	4.7	0.45	5.4	0.45	6.6	0.74	7.6	1.13	8.1	0.86	7.6	1.13	8.1	0.86	4.3	0.40			8.5	0.80	14.8	1.41
9	5.0	0.45	5.7	0.46	6.9	0.74	7.9	1.12	8.5	0.87	7.9	1.12	8.5	0.87	4.9	0.43			9.4	0.90	15.5	1.25
10	5.8	0.47	6.5	0.49	8.1	0.73	9.0	1.12	9.5	0.92	8.1	1.12	9.5	0.92	5.7	0.58			10.5	0.99	16.1	1.73
11	6.6	0.56	7.3	0.57	9.4	0.80	10.2	1.12	10.6	0.99	10.2	1.12	10.6	0.99	6.8	0.68			11.6	1.05	16.8	1.90
12	7.3	0.61	8.1	0.61	10.9	0.99	11.2	1.13	11.9	1.12	11.2	1.13	11.9	1.12	7.8	0.68			12.5	1.11	17.4	0.75
13	8.1	0.68	9.0	0.71	12.2	1.00	12.2	1.17	12.9	1.19	12.2	1.17	12.9	1.19	8.8	0.73			13.6	1.18	18.2	0.85
14	9.2	0.89	9.9	0.81	13.5	1.22	13.3	1.31	14.0	1.27	13.3	1.31	14.0	1.27	10.0	0.91			14.8	1.26	18.5	0.97

TABLE 3—Age (years) of Attainment of Mineralization Stages of Teeth of the Female Maxilla.

Stage	Incisors						Premolars						Molars					
	Central		Lateral		Canine		First		Second		First		Second		Third			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
1							4.0	0.56					3.7	0.41	9.2	1.38		
2							3.8	0.48					4.2	0.54	9.9	1.36		
3							3.4	0.10	3.4	0.10	4.3	0.57	4.6	0.52	10.5	1.37		
4							3.7	0.26	3.7	0.26	4.7	0.60	5.1	0.57	11.1	1.42		
5			3.6	0.15	3.6	0.13	4.4	0.46	5.3	0.68			5.6	0.58	11.8	1.43		
6	3.6	0.14	3.8	0.40	4.1	0.49	5.1	0.56	5.9	0.65			6.3	0.66	12.7	1.49		
7	3.8	0.38	4.5	0.51	4.9	0.57	5.8	0.59	6.8	0.72	3.6	0.27	7.1	0.74	13.6	1.57		
8	4.6	0.41	5.2	0.56	5.6	0.61	6.6	0.66	7.7	0.81	4.0	0.44	8.1	0.76	14.4	1.55		
9	4.9	0.41	5.5	0.57	5.9	0.63	6.9	0.67	8.0	0.81	4.6	0.44	9.0	0.81	15.1	1.38		
10	5.7	0.49	6.3	0.61	7.0	0.72	7.8	0.73	8.8	0.80	5.4	0.56	10.0	0.85	16.1	1.39		
11	6.6	0.62	7.3	0.70	8.2	0.76	8.7	0.80	9.7	0.86	6.3	0.62	11.0	0.93	16.9	1.24		
12	7.4	0.76	8.1	0.73	9.4	0.81	9.7	0.90	10.6	0.90	7.2	0.67	11.8	1.02	17.7	1.07		
13	8.2	0.78	8.8	0.77	10.6	0.86	10.6	0.90	11.5	1.01	8.2	0.68	12.6	1.11	18.4	1.00		
14	9.3	0.80	9.7	0.83	11.9	1.04	11.8	0.96	12.6	1.10	9.2	0.74	13.6	1.27	18.8	0.70		

TABLE 4—Age (years) of Attainment of Mineralization Stages of Teeth of the Female Mandible.

Stage	Incisors						Premolars						Molars					
	Central		Lateral		Canine		First		Second		First		Second		Third			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
1									4.2	0.70					3.7	0.37	9.4	1.55
2									3.8	0.57					4.1	0.52	10.1	1.57
3							3.4	0.09	4.3	0.59					4.6	0.51	10.6	1.49
4							3.7	0.28	4.7	0.60					5.1	0.56	11.3	1.58
5							4.3	0.48	5.2	0.65					5.7	0.57	11.9	1.56
6	3.6	0.20	3.7	0.28	4.1	0.49	5.0	0.54	5.9	0.74					6.3	0.66	12.8	1.63
7	3.7	0.29	4.3	0.45	4.8	0.52	5.8	0.63	6.7	0.76			3.6	0.27	7.2	0.74	13.7	1.66
8	4.3	0.41	5.0	0.50	5.6	0.58	6.6	0.67	7.5	0.82			4.0	0.45	8.1	0.74	14.5	1.52
9	4.6	0.40	5.2	0.50	5.9	0.60	7.0	0.68	7.8	0.83			4.6	0.45	9.0	0.79	15.4	1.56
10	5.3	0.44	5.9	0.53	6.9	0.68	7.9	0.76	8.6	0.91			5.3	0.55	10.0	0.86	16.3	1.40
11	6.1	0.52	6.7	0.60	8.1	0.79	8.9	0.81	9.6	1.02			6.3	0.60	11.0	0.93	17.3	1.41
12	6.7	0.53	7.3	0.69	9.2	0.80	9.9	0.86	10.6	1.06			7.2	0.65	11.8	0.91	17.7	1.44
13	7.3	0.65	8.0	0.74	10.3	0.85	10.9	0.93	11.6	1.12			8.2	0.71	12.6	0.98	18.2	1.62
14	8.1	0.77	8.8	0.78	11.4	0.92	11.9	1.03	12.8	1.25			9.2	0.75	13.8	1.28	18.3	2.23

than is skeletal mineralization because tooth formation is modified much less by malnutrition and hormone imbalance [16-18].

The sex differences in the age of mineralization of the teeth observed in the present study are similar to those reported in less extensive serial studies [3,8,9,11]. When sex is unknown, the stages of the canines would be the least accurate for age determination because the sex differential in age is greatest for these teeth [14,15]. Four cases (Table 5) were selected at random to demonstrate age determination from mineralization stages of mandibular teeth by using Tables 2 and 4. Age estimation was more accurate when the table appropriate to the sex was used. When the table for the opposite sex was used, the error was greatest at the canines for individuals A, B, and D, and second to greatest for female C.

More accurate age estimation can be achieved by choosing teeth that show the least variability in age. The mandibular central incisor and first molar showed the least variance, whereas the males varied considerably in age of first premolar mineralization. For male A in Table 5, the error in age estimation from the mean ages listed in Table 2 was greatest for the first premolar and least for the central incisor and first molar.

In agreement with Garn et al [13], this study found that the variability in age of tooth formation increased with chronological age, but after age 16 to 17 the variability decreased during the final stages of root formation and apical closure of the third molars. Variability in ages of third molars was relatively large for both sexes. For the other teeth, variability was greater among the males. Although this conclusion does not agree with that of Nolla [9], it is in harmony with those of Garn et al [16], who found that girls are more consistent than boys in all developmental timings, including the teeth. This consistency was attributed [16] to influence of the X chromosome, whereas the local sex differential in the canine region was attributed to influence of the Y chromosome [12].

### Summary

The ages at which the maxillary and mandibular teeth of 121 boys and 111 girls reached 14 mineralization stages were determined from serial cephalograms at the Burlington Growth Centre. The present data are more comprehensive than any previously available and can be applied to chronological age determinations in juveniles of indefinite age, and of specimens in anthropological and forensic investigations. The sexes differed in the age at which they attained the stages of mineralization, with the canines demonstrating the greatest difference. In each sex, the ages at identical stages were similar for the corresponding teeth in the maxilla and mandible. Variability in age was greater among the males, especially for the first premolars, and increased with age, except for the third molars. Variability in age of third molar mineralization was greater in females and diminished among both sexes at late stages of root formation.

### Acknowledgments

This study was made possible by use of materials from the Burlington Growth Centre, which was supported by funds provided by grants 605-7-299 and 605-7-733 of the National Health Grants of Canada. The stages of mineralization of the teeth were scored by Dr. K. Cheung.

### References

- [1] Demirjian, A., Goldstein, H., and Tanner, J. M., "A New System of Dental Age Assessment," *Human Biology*, Vol. 45, No. 2, 1973, pp. 211-227.
- [2] Fanning, E. A., "A Longitudinal Study of Tooth Formation and Root Resorption," *New Zealand Dental Journal*, Vol. 57, No. 270, 1961, pp. 202-217.

TABLE 5—Examples of Age Determination from Teeth Mineralization Stages.

Subject	Age, years	Sex	Determination	Mandible												
				Incisors			Canine			Premolars			Molars			
				1	2	7	6	6	4	4	9	1	2	3		
A	5.0	male	mineralization stage	9												
			age from Table 2	5.0	4.8	4.8	4.8	5.6	4.8	4.8	4.9	4.8	4.8	4.8	4.8	...
			difference from actual age	0	-0.2	-0.2	-0.2	+0.6	-0.2	-0.2	-0.1	-0.2	-0.2	-0.2	-0.2	...
B	10.0	male	age from Table 4	4.6	4.3	4.1	5.0	4.7	4.6	4.6	4.6	4.6	4.6	4.6	...	
			difference from actual age	-0.4	-0.7	-0.9	0	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	...
			mineralization stage	14	13	11	11	11	11	11	14	10	10	10	10	1
			age from Table 2	9.0	9.4	10.2	10.6	10.6	10.5	9.1	9.1	9.1	9.1	9.1		
			difference from actual age	-0.9	-0.6	+0.2	+0.6	+0.6	+0.5	-0.9	-0.9	-0.9	-0.9	-0.9		



- [3] Garn, S. M., Lewis, A. B., Koski, K., and Polacheck, D. L., "The Sex Difference in Tooth Calcification," *Journal of Dental Research*, Vol. 37, No. 3, 1958, pp. 561-567.
- [4] Gleiser, I. and Hunt, E. E., "The Permanent Mandibular First Molar, Its Calcification, Eruption and Decay," *American Journal of Physical Anthropology*, Vol. 13, No. 2, 1955, pp. 253-284.
- [5] Gustafson, G., *Forensic Odontology*, Staples Press, London, 1966, pp. 102-118.
- [6] Hotz, R., Boulanger, G., and Weissaupt, H., "Calcification Time of Permanent Teeth in Relation to Chronological and Skeletal Age in Children," *Helvetica Odontologica Acta*, Vol. 3, No. 1959, pp. 4-9.
- [7] Johanson, G., "Age Determinations from Human Teeth," *Odontologisk Revy*, Vol. 22, Suppl. No. 21, 1971, p. 22.
- [8] Moorrees, C. F. A., Fanning, E. A., and Hunt, E. E., "Age Variation of Formation Stages in Ten Permanent Teeth," *Journal of Dental Research*, Vol. 42, No. 6, 1963, pp. 1450-1502.
- [9] Nolla, C. M., "The Development of the Permanent Teeth," *Journal of Dentistry for Children*, Vol. 27, No. 4, 1960, pp. 254-266.
- [10] Prahj-Andersen, B. and van der Linden, F. P. G. M., "The Estimation of Dental Age" in *Transactions*, European Orthodontic Society, The Hague, 1973, pp. 535-541.
- [11] Sapoka, A. M. and Demirjian, A., "Dental Development of the French Canadian Child," *Journal of the Canadian Dental Association*, Vol. 37, No. 3, 1971, pp. 100-104.
- [12] Tanner, J. M., *Growth at Adolescence*, Blackwell Scientific Publications, Oxford, 1962, pp. 40-73.
- [13] Garn, S. M., Lewis, A. B., and Polacheck, D. L., "Variability of Tooth Formation," *Journal of Dental Research*, Vol. 38, No. 1, 1959, pp. 135-148.
- [14] Thompson, G. W., Anderson, D. L. and Popovich, F., "Sexual Dimorphism in Dentition Mineralization," *Growth*, Vol. 39, 1975, pp. 289-301.
- [15] Cameron, J. M. and Sims, B. G., *Forensic Dentistry*, Churchill Livingstone, London, 1974, pp. 31-38.
- [16] Garn, S. M., Lewis, A. B., and Kerewsky, R. S., "Genetic, Nutritional, and Maturational Correlates of Dental Development," *Journal of Dental Research*, Vol. 44, Suppl. to No. 1 1965, pp. 228-243.
- [17] Garn, S. M., Lewis, A. B., and Blizzard, R. M., "Endocrine Factors in Dental Development," *Journal of Dental Research*, Vol. 44, Suppl. to No. 1, 1965, pp. 243-258.
- [18] Stewart, T. D., "New Developments in Evaluating Evidence from the Skeleton," *Journal of Dental Research*, Vol. 42, Suppl. to No. 1, 1963, pp. 264-273.
- [19] Fanning, E. A. and Brown, T., "Primary and Permanent Tooth Development," *Australian Dental Journal*, Vol. 16, No. 2, 1971, pp. 41-43.
- [20] Furuhashi, T. and Yamamoto, K., *Forensic Odontology*, Charles C. Thomas, Springfield, Ill., 1967, pp. 68-70.
- [21] Thompson, G. W., Popovich, F., and Anderson, D. L., "Third Molar Agenesis in the Burlington Growth Centre in Toronto," *Community Dental and Oral Epidemiology*, Vol. 2, No. 4, 1974, pp. 187-192.

Burlington Growth Centre  
 124 Edward St.  
 Toronto, Ontario M5G 1G6  
 Canada