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Age Variation of Formation Stages for Ten Permanent Teeth

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Differences in the development among children of the same chronologic age have led to the concept of physiologic age as a means to define progress toward completeness of development or maturity in the individual child. Thus, physiologic age or its frequently used synonyms, biologic and developmental age, are measures for describing the status of an individual child, whereas chronologic or calendric age convey only a rough approximation of this status because of the range in development observed for any given age.

Physiologic age is estimated by the maturation of one or more tissue systems, and it is best expressed in terms of each system studied. Maturation is scaled by the occurrence of one or the sequence of multiple events that are irreversible.

The dentition is one of the four systems used. The other three developmental indicators refer to bone development, secondary sex characters, and stature or weight.

Dental age can be determined by the emergence and by the formation of the teeth. Tooth formation is superior to tooth emergence for assessing dental maturation, because the majority of the teeth can be studied at each examination. In contrast, emergence is only a specific phase of short duration in the continuous process of eruption, rarely observed for more than one or two teeth at a time, if at all. Emergence is also influenced markedly by environmental factors such as loss of deciduous predecessors and the lack of space in the dental arch, explaining some part of the variation in root length at emergence.^{1, 2}

Dental maturation is of particular significance for the timing of growth changes of the dentition in the living³ and for aging skeletal specimens when only jaws remain.⁴ Nevertheless, inferences of somatic maturation from either tooth formation or tooth emergence should be made with caution, because the relation of dental development and somatic development, as estimated from bone formation in the hand-wrist region and the appearance of secondary sex characteristics, is not, as yet, fully explored.⁵

In general, a low-to-medium degree of association exists for all maturity indicators, but during the adolescent growth phase, the measures of somatic development are more highly correlated.⁶

The purpose of the present study is to provide norms of the formation of ten permanent teeth, namely, the maxillary incisors and all eight mandibular teeth. The

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findings furnish ages of attainment for fourteen arbitrarily selected stages of tooth development and the variations observed among the group studied. Apart from describing a developmental process, they serve to rate individual children, expressing the degree of advancement or retardation by means of standard scores.

Materials and Methods

The collaboration of the Forsyth Dental Infirmary in the longitudinal studies of child health and development, conducted at the School of Public Health, Harvard University, under the direction of Dr. Harold C. Stuart,⁷ has already resulted in two studies of the chronology of tooth formation.^{8, 9}

These investigations have been extended, augmenting the material by analysis of the longitudinal data at the Fels Research Institute at Yellow Springs, Ohio, that were generously made available to the Forsyth by Dr. Stanley M. Garn, chairman of the Department of Human Growth and Genetics.

The development of the permanent maxillary and mandibular central and lateral incisors was studied in intraoral radiographs of Boston children from the Stuart material. From the total of 134 children, the data of 48 males and 51 females were utilized, as having the most satisfactory radiographic records.

The frequent lapse in observation after ten years of age, owing to conditions imposed by World War II, made it impossible to determine the formation of the mature root length for the permanent canines, premolars, second, and third molars; and therefore, the Fels material was used for studying the permanent mandibular posterior teeth ($C-M_3$).

The lateral or "oblique" jaw radiographs for the Fels program were obtained at half-yearly intervals by Dr. Arthur B. Lewis. From this collection, samples of 136 boys and 110 girls were selected for analysis. Dental health was excellent in the North American white children of the middle-socioeconomic group included in the Fels material.

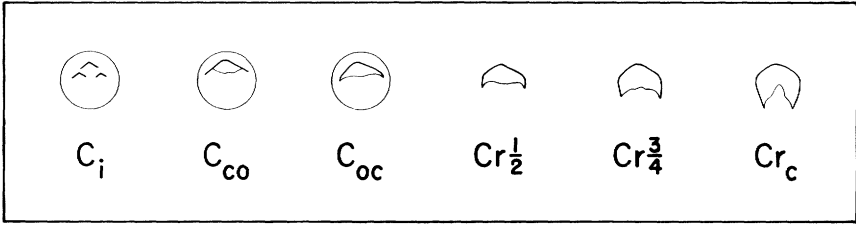
The maxillary posterior teeth have not been studied because their image cannot be identified clearly on lateral jaw radiographs, owing to superposition of left and right sides. However, the Fels data were also used for obtaining the chronology of the formation and resorption of the deciduous mandibular canine and molars.⁴

Dental development was determined by inspecting radiographs and assigning a rating according to consecutive stages defined in Table 1 and shown in Figure 1 for single-rooted teeth, and in Figure 2 for multiple-rooted teeth. These stages, already used by the second author in previous studies,⁹ conform with slight modification to those used by other investigators.^{8, 10-12}

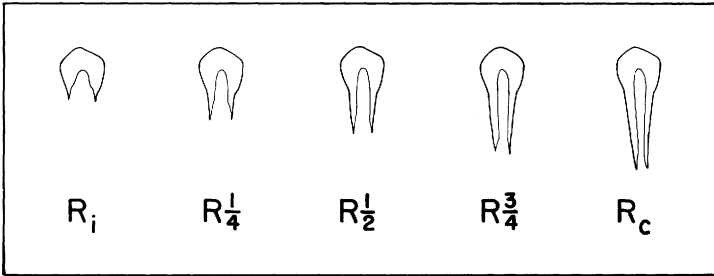
The reliability of distinguishing between two stages of root development has been tested from double determination of 874 intraoral radiographs with an interval of at least three months by Grøn.² Agreement in the ratings existed in 90 per cent of the double determinations of the mandibular cheek teeth, and in 75 per cent of the maxillary and mandibular incisors, while the differences that occurred never exceeded one stage.

A cumulative percentage frequency was obtained for a stage of tooth formation by counting the number of children at each pertinent age having attained or passed this

Crown



Root



Apex

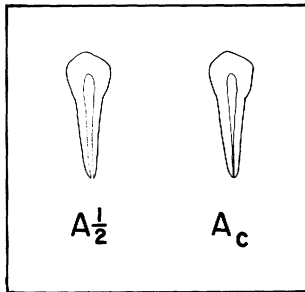


FIG. 1.—Stages of tooth formation for assessing the development of single-rooted teeth

TABLE 1
TOOTH-FORMATION STAGES AND
THEIR CODED SYMBOLS

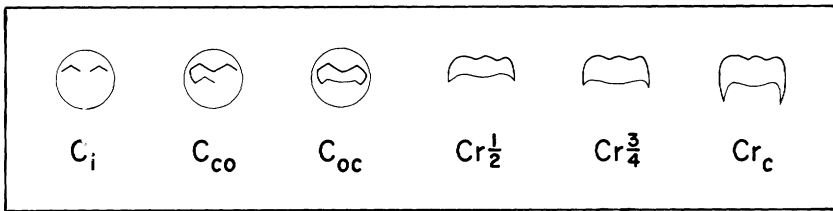
Stage	Coded Symbol
Initial cusp formation	<i>C_i</i>
Coalescence of cusps	<i>C_{co}</i>
Cusp outline complete	<i>C_{oc}</i>
Crown $\frac{1}{2}$ complete	<i>Cr_{1/2}</i>
Crown $\frac{3}{4}$ complete	<i>Cr_{3/4}</i>
Crown complete	<i>Cr_c</i>
Initial root formation	<i>R_i</i>
Initial cleft formation	<i>Cl_i</i>
Root length $\frac{1}{4}$	<i>R_{1/4}</i>
Root length $\frac{1}{2}$	<i>R_{1/2}</i>
Root length $\frac{3}{4}$	<i>R_{3/4}</i>
Root length complete	<i>R_c</i>
Apex $\frac{1}{2}$ closed	<i>A_{1/2}</i>
Apical closure complete	<i>A_c</i>

stage as the numerator and the total number of children examined at that age as the denominator.

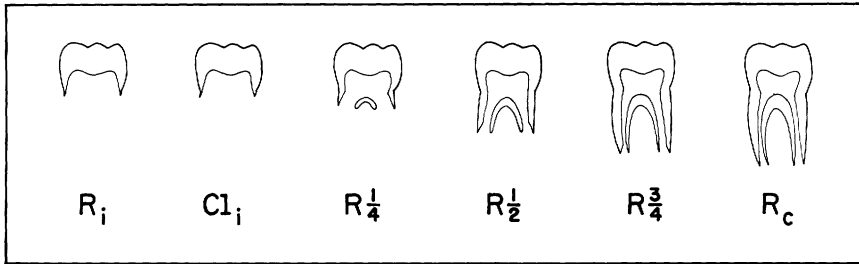
These percentages of attainment were converted into normal deviates by referring to a table of areas under the normal curve. The ages were transformed in the logarithms of conceptional age, based on a gestation period of nine months. A common slope for the attainment lines of all stages of all teeth was assumed on the basis of findings from a previous study on the Stuart material,⁹ confirmed by plotting the cumulative frequencies of the present data on arithmetic probability paper.

As a consequence, a common standard deviation of 0.042 log. conceptional-age units was used to obtain weighted estimates of the mean attainment age for each stage from the percentages of attainment at different ages. Percentages less than 5 and greater

Crown



Root



Apex

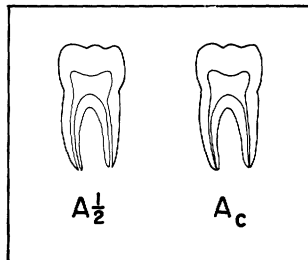


FIG. 2.—Stages of tooth formation for assessing the development of permanent mandibular molars

than 95, as well as those from samples smaller than 15 individuals, were eliminated.

By averaging these estimates, the mean attainment age for each developmental stage was determined. Subsequently, these mean ages, in units of logarithmic conceptual age, were transformed into chronologic age, and the plus and minus one and two standard deviation age limits were also calculated.

Results

The chronology of the formation of the permanent mandibular posterior teeth ($C-M_3$), as well as the later stages of development of the permanent maxillary and mandibular incisors (I_1 and I_2), is presented in graphic form for each sex (Figs. 3–6).

The permanent mandibular teeth ($C-M_3$) were formed after birth, except the first molars of early maturers. In terms of averages, initial crown formation of the permanent canine occurred at the age of 6 months, at 1.8 years for the first premolar, at 3.0 years for the second premolar, at 3.5 years for the second molar and at approximately 9.4 years for the third molar.

The average child in the first grade of school (6–6.5 years) had just completed crown formation of the second molars and second premolars, all other teeth, except the third molar, having reached this developmental level earlier.

At twelve years of age, the mature root length was attained for all permanent teeth, again with the exception of the third molar, for which tooth crown completion was achieved.

The length of time required for the formation of tooth crowns, obtained as the mean time interval between initial calcification and the crown completed stage, was 2.1 years for first molars and 2.8 years for second and third molars. No data were available for the incisors, but the formation period of premolar crowns was longer than that of the molars, namely 3.1–3.4 years, and 3.5 years for the canine.

Root formation, again expressed as a mean time interval (Cr_c-R_c), occurred in 3.3 years for the maxillary central incisor, in 3.6 years for the mandibular first molar, in 4.8 years for the second molar, and in approximately 4.5 years for the third molar. These findings refer to the mesial roots of the three molars, the development of the distal roots demanding an additional 0.2 to 0.3 years.

The time lapse for root formation of the maxillary lateral incisor as well as for the mandibular canine and the two premolars can not be described as readily in general terms. Sex differences were more pronounced for the root maturation of these teeth (0.41–1.31 years) than for the three molars (0.05–0.33 years). The canine and two premolar roots of females were formed in 4.6–4.9 years, while in the average male, 5.3 and 5.4 years were required for the development of first and second premolar roots, and as much as 6.2 years for the canine.

Root formation of the maxillary lateral incisor occurred in 4 years in the case of males and 0.6 years faster in females. Data for mandibular incisors were not available.

In contrast to root formation, the length of time required for crown development was practically the same in males and females, differences occurring within a narrow range from 0.02–0.10 years. However, sex differences for separate stages of crown formation were occasionally greater, although never exceeding 0.25 years for the

mandibular posterior teeth. Little information was available for the incisors, although a sex difference of 0.5 years was noted for the maxillary central incisor at the crown-completion stage and of 0.2 years for the lateral incisor at the same stage.

In the attainment of various stages of root development in first molars, the average female was only 0.14 years or less advanced in comparison to the average male. For the stages of root maturation in first premolars and second molars the sex difference centered around 0.5 years. It was greater (0.5–0.9 years) for attainment of the half-root length and subsegment stages for second premolars.

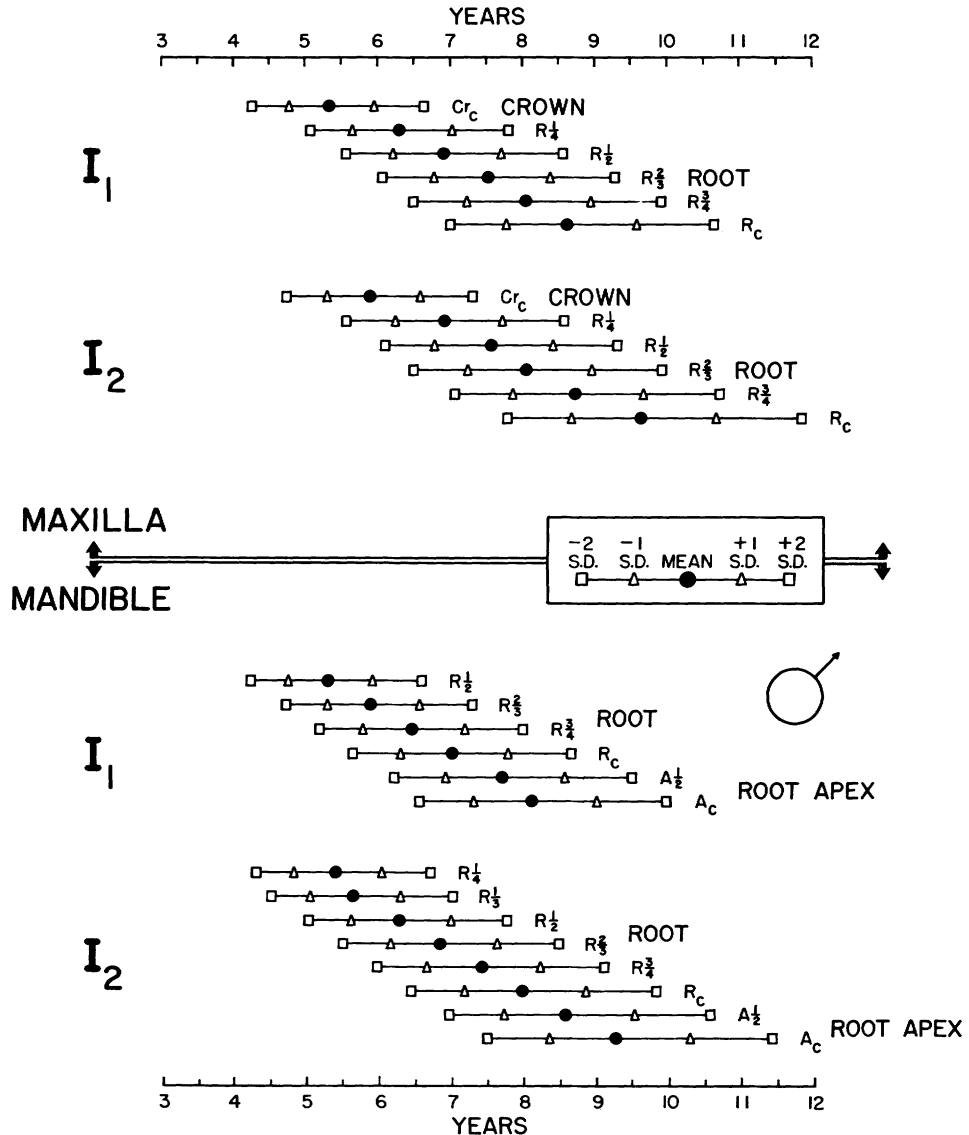


FIG. 3.—Norms of the formation of permanent maxillary and mandibular incisor roots of males, including the crown-complete stage of the maxillary incisors.

The most pronounced retardation in root development of males (0.8-1.4 years) was observed for the mandibular canine after stage $R_{1/4}$. This tooth was also reported to have had the greatest sex difference in mesiodistal crown diameter¹³ and in emergence. The $R_{3/4}$ stage, at which teeth were most frequently observed to break through the gums,² showed a 1.3 years delay in the canine of males, while Hurme¹⁴ has tabulated the mean sex difference in its emergence at just below one year.

The disagreement between these two findings is actually smaller than 0.3 years because mandibular canines of females tend to emerge when the root has passed the three-quarter stage.²

The rate of tooth development is not constant when judged from the mean inter-

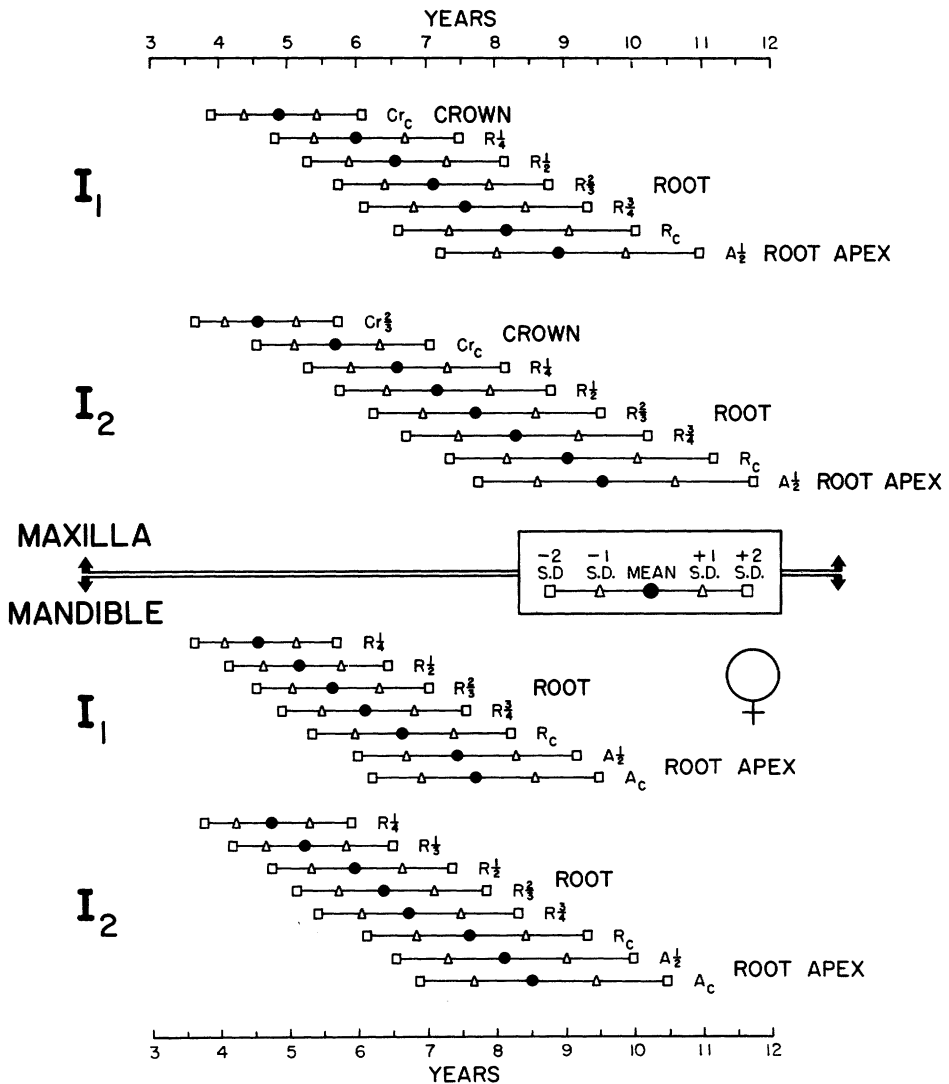


FIG. 4.—Norms of the formation of permanent maxillary and mandibular incisor roots of females, including terminal stages of crown formation of the maxillary incisors.

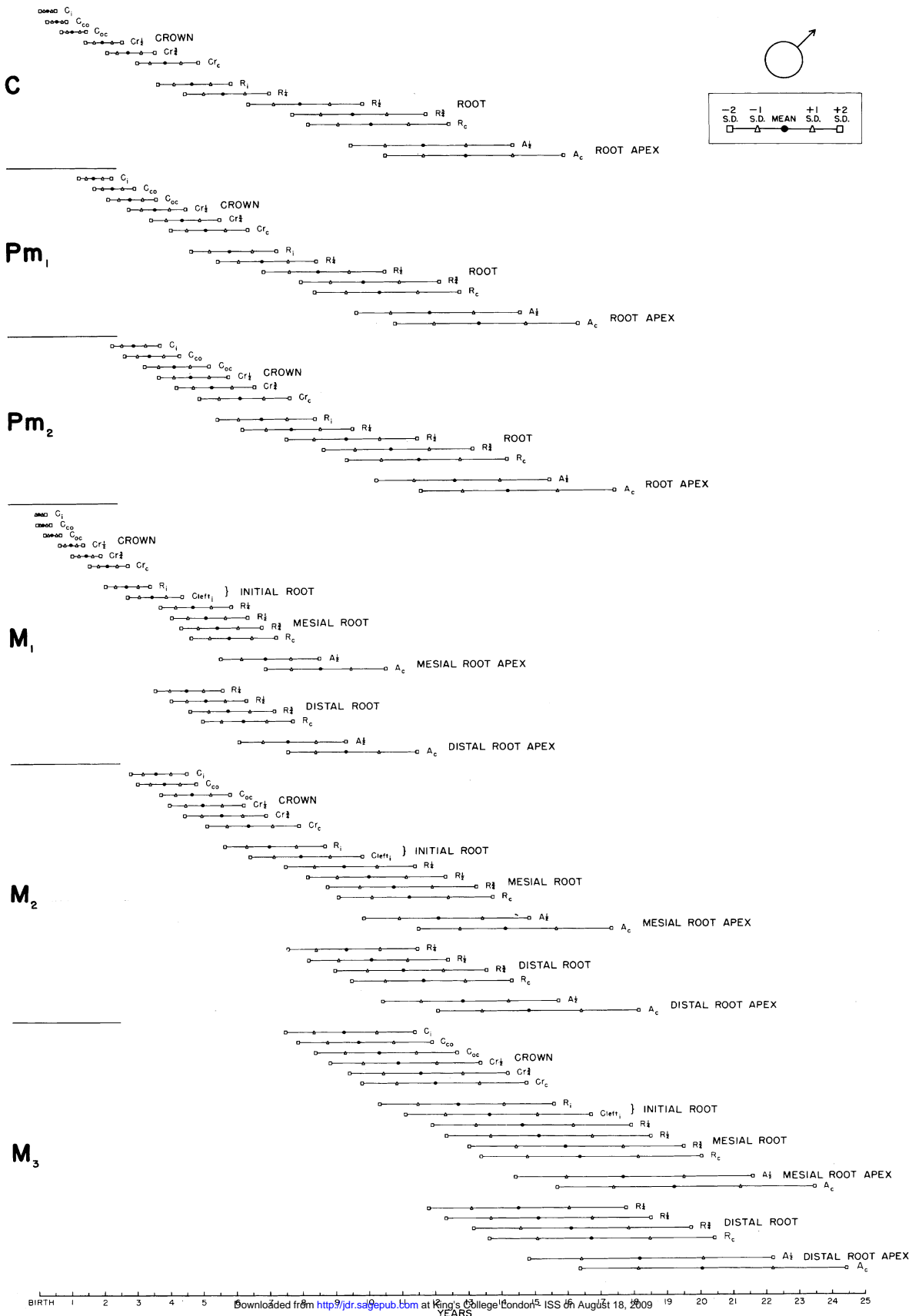


FIG. 5.—Norms of tooth formation of permanent mandibular canines, premolars, and molars of males

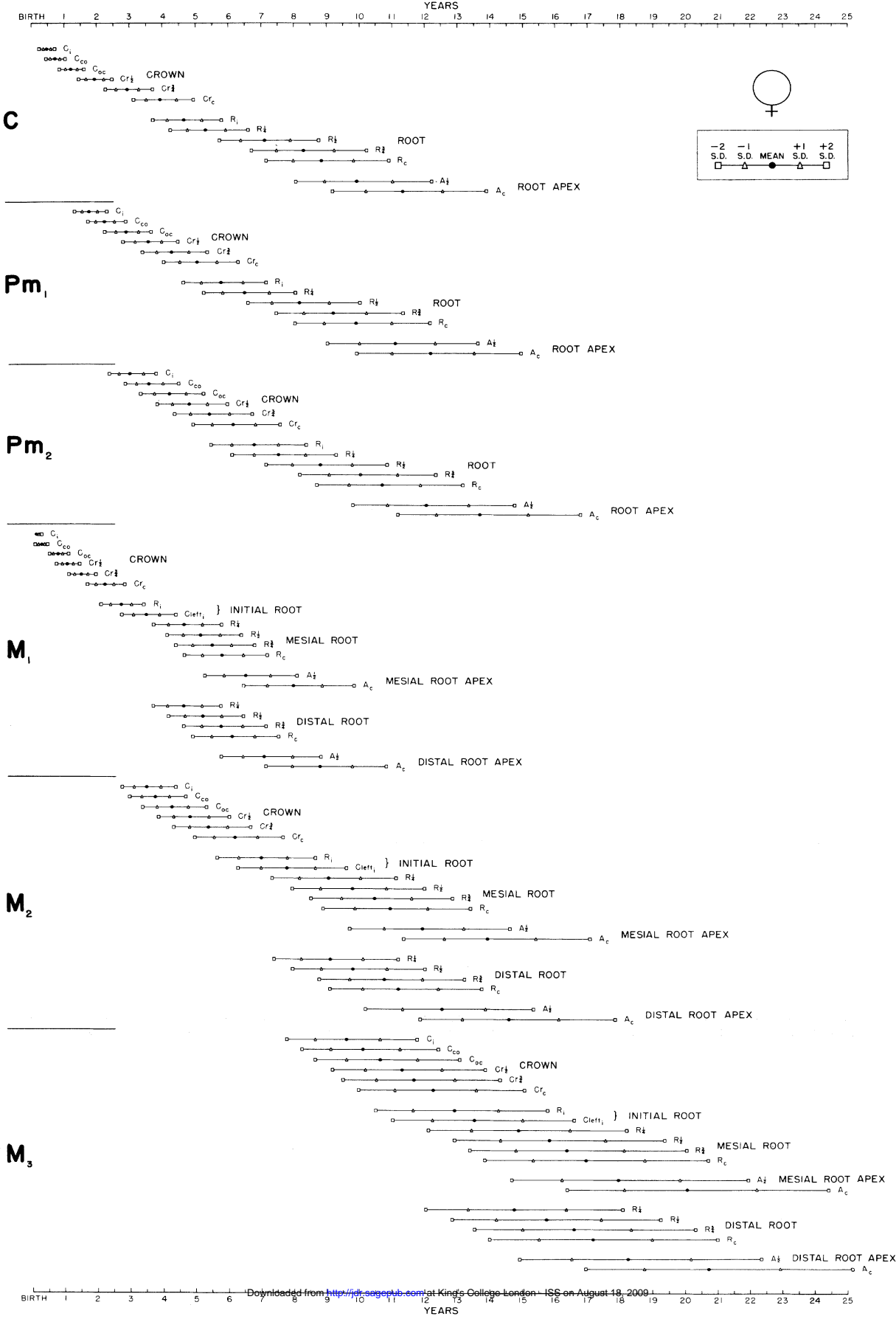


FIG. 6.—Norms of tooth formation of permanent mandibular canines, premolars, and molars of females

val between stages. For instance, the formation of the second quarter of the mandibular canine and premolar roots required 1.3 years for the second premolar in females and 2.3 years for the canine in males. The fourth quarter-root of these teeth was formed in only 0.7 and 0.6 years, respectively. Statistical description of the individual variation of the duration of each stage could not be determined from the available material. Radiographs must be obtained with sufficient frequency to pinpoint the actual beginning of each stage.

The variance in attainment of developmental stages was the same for males and females, owing to the assumption of a common slope for all stages of all teeth for both sexes, as discussed above under methods. The range of variation, expressed by the plus and minus 2 standard deviation limits, was less than 1 year for crown development in early infancy. Individual differences became more pronounced after 2 years of age and the span (± 2 S.D.) was 3–5 years for the more mature stages of root formation. At apical closure, it was about 6 years for premolars and second molars, or as large as 8 years for the third molar.

Thus, half-year difference in attainment of a given stage may be an insignificant finding for later stages of tooth formation, or it may constitute a marked deviation in infancy. For this reason, the expression of tooth formation in terms of standard scores is preferred to assigning a dental age.⁴

The charts were therefore designed to express tooth formation of an individual child directly in terms of standard scores. These developmental ratings are read for each tooth separately, facilitating comparison of the maturation of different teeth in the same child.

The charts are composed of segments, one for a specific tooth, in which the chronology of its development is recorded graphically by horizontal bars for each stage. On a horizontal bar, the mean age of attainment and the plus and minus one and two standard-deviation limits are indicated by symbols.

A scale is provided at the top and bottom of the charts for indicating chronologic age. The assessment of tooth formation is recorded by a check mark at the appropriate stages for the different teeth. When the rating is intermediate between two stages, the check mark is placed at the two horizontal bars that indicate the interpolation limits.

By drawing a vertical line through corresponding points on the age scales, the rating of tooth development of a child is read directly in standard scores at the points of intersection of this vertical line and the horizontal bars for each specific tooth formation stage.

Interpolation is performed by averaging the two standard score values at the interpolation limits. If necessary, the weighting of an interpolation is indicated by placing a dot at an appropriate level between stages on the vertical line.

To illustrate the use of the charts for the assessment of dental development, a radiograph of a child is reproduced in Figure 7.

The mandibular central incisors of this 6.75-year-old boy attained their mature root lengths (R_C), and two-thirds of his mandibular lateral incisor root lengths were completed (Fig. 7).

Inspection of Figure 8, consisting only of the relevant data, shows that the mandibular central incisor is at the -0.3 standard score level and the lateral incisor at

the mean for its stage ($R_{2/3}$). According to the root formation of his mandibular incisors, this boy's dental development corresponded closely to that expected for his chronologic age.

The procedure for interpolating ratings between stages is shown in Figure 9, referring to the mandibular molars of a 6-year-old girl. The mesial root of the permanent first molar approaches root-length complete, the distal root has attained three-quarters of its length, and the crown of the second molar is intermediate between the three-quarters and the completed-crown-form stage.

When reference is made to Figure 9, it is noted that the vertical line drawn at the child's chronologic age (6 years) intersects stage $R_{3/4}$ for the mesial root of the first molar at the $+0.9$ standard score level and stage R_C at the $+0.4$ standard score level. The final assessment of the first molar's mesial root is weighted toward the completed root-length phase (2:1), namely:

$$\frac{(2 \times 0.4) + (1 \times 0.9)}{3} = +0.6 \text{ standard score.}$$



FIG. 7.—Dental radiograph of the permanent mandibular incisors of a 6.75-year-old boy

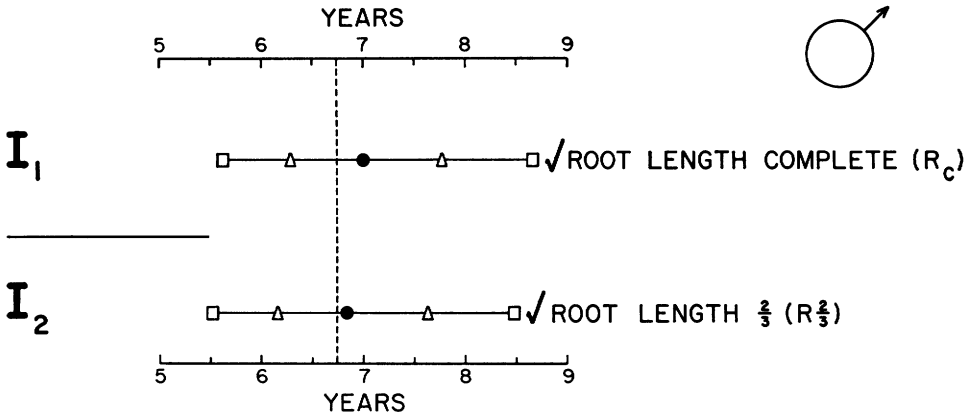


FIG. 8.—The assessment of the formation of the permanent mandibular incisors shown in Figure 7 in terms of the norms shown by reproducing only the relevant section of Figure 3. The attainment of the complete root length (R_c) of the central incisor and two-thirds of the root length ($R_{2/3}$) of the lateral incisor in this 6.75-year-old boy corresponds closely to mean ages of attainment for these stages.

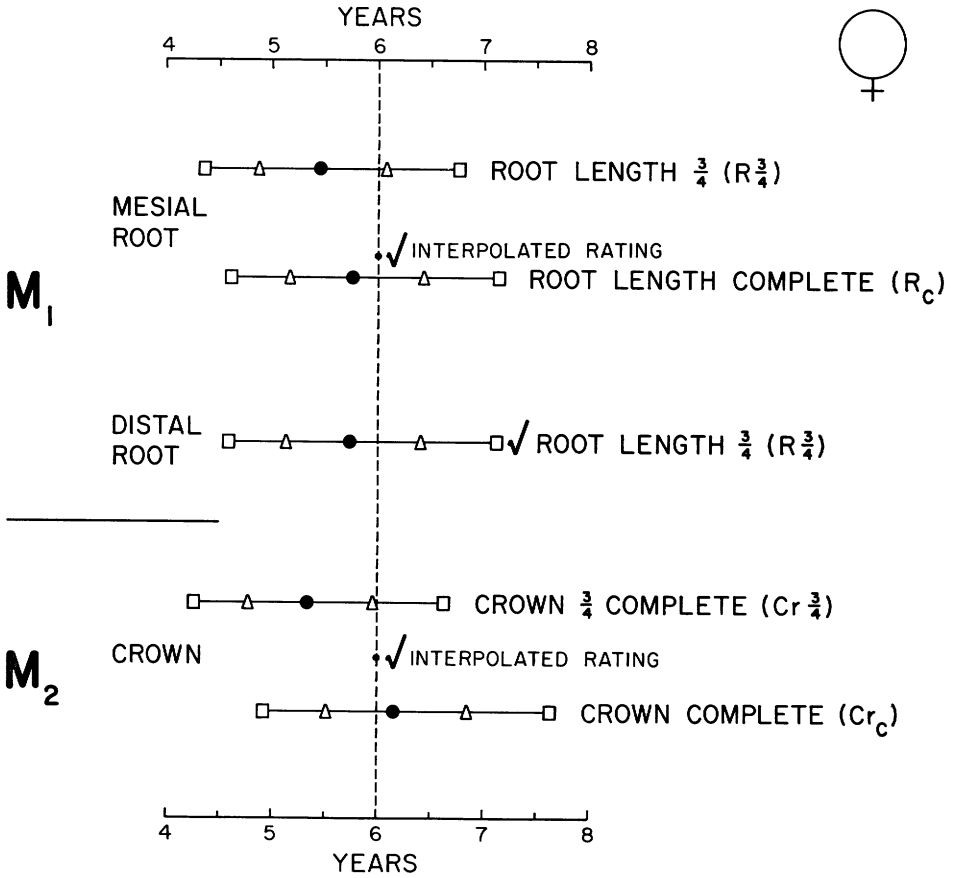


FIG. 9.—Interpolation between stages shown for permanent mandibular first and second molars of a 6-year-old girl, reproducing only the relevant section of Figure 6. The formation of the mesial and distal roots of the first molar and the crown of the second molar corresponds to $+0.6$, $+0.4$, and $+4$ standard scores, respectively, in terms of the norms. The interpolation of the rating for the mesial root of the first molar between $R_{3/4}$ and R_c and of the crown of the second molar between $Cr_{3/4}$ and $Cr.c$ is explained in the text.

The maturation of the distal root of the permanent first molar of this girl at the $+0.4$ standard score level closely approximated that of the mesial root. Correspondingly, the interpolated evaluation for the crown of the permanent second molar (Fig. 9) resulted in a $+0.4$ standard score rating $(1.1 - 0.25)/2$, in terms of the norm.

Discussion

The use of these charts for the purpose of determining the dental maturation of a particular child from radiographs presents a number of problems. Ideally, if the permanent mandibular canine of an 8-year-old boy is exactly at stage $R_{1/2}$, dental age would correspond to the mean age of attainment of this stage for the canine among boys.

In practice, however, the assessment of dental maturation will be affected by the following factors: (1) the applicability of these normative data to the population to which an individual child belongs; (2) the possible variation between rates of development of different teeth in a given child; (3) the experience of the rater in recognizing sequential stages of tooth formation; (4) the availability of earlier or later records of the same child to serve as a basis of reference when rating tooth development; and (5) the span of time between the occurrence of one stage of development and the next.

The first of these factors applies to the use of norms of any type. Until much more is known about the determination of the pattern of tooth formation, one cannot properly anticipate that other populations of children will follow the same time schedules as the present ones. Thus, in another population, the children may pass through these stages of dental development in the same sequences, except possibly for the cleft stages in taurodont molars, but consistently earlier or later.

Results of the application of the findings at Forsyth have already shown that the posterior mandibular teeth of 8- to 12-year-old Boston children mature approximately one-half year later than suggested by the normative data obtained from Ohio children.

Owing to the relative dearth of data on the rate of dental development, as observed radiographically, the charts have usefulness and applicability. Nevertheless, final judgment as to the universality of this chronology of tooth formation must await the study of other groups.

The second factor cited above is also in need of further study. In general, it seems reasonable to arrive at a single standard score rating for a child. Since little is known about the degree of consistency in the development of different teeth within an individual, it is desirable to express the variation encountered in the formation of the teeth studied, as shown directly in the charts presented, thereby paralleling the handling of developmental centers in the hand-wrist according to the Red Graph Method.¹⁵

The experience of the rater is also a factor that enters into the use of many norms. Testing has shown that the stages selected are quite explicitly defined and that a high degree of uniformity between observers can be achieved.

It is, of course, essential that an optimal radiographic technique be used to reproduce images of the teeth with minimal distortion. Foreshortened or elongated projections of a developing tooth affect the reliability of assessment. In this connection it

may be emphasized that radiography of incisors prior to emergence, especially in the maxilla, requires expert technique. Furthermore, satisfactory reproduction of the posterior mandibular teeth for determining their development is obtained best in lateral jaw radiographs.

The availability of a series rather than a single isolated film adds considerably in refining the precision of judgment. In a longitudinal study, the assessment can be made with reference to the mature form of either crown or root, as the case may be. In cross-sectional material, the evaluation of root length is carried out by comparing each tooth with the roots and alveolar outlines of adjacent and more mature teeth, such as the permanent first molar, when considering premolar and second molar root lengths, and the deciduous second molar, as a guide for studying the roots of the permanent first molars. Lack of satisfactory landmarks make the determination of root length of maxillary and mandibular incisors less accurate than for the other mandibular teeth.

The span of time between stages is another point where the experience of the rater may well contribute to increased precision in the determination of dental maturation. It is only rarely that a tooth is seen exactly at a stage. Consequently, if one limits oneself strictly to the stages as defined and does not recognize gradation between them, one would be more commonly forced to make statements that a given tooth has passed stage $R_{1/4}$, for instance, but has not yet attained stage $R_{1/2}$. If the limits of this evaluation are to be narrowed to a single rating, two procedures are available. One may arbitrarily assign a standard score midway between the upper and lower values on the grounds that this figure represents the average level of dental maturation in a random sample of individuals who are observed to be between two stages. Or, one may make a more refined reading of the radiograph in order to estimate how far this child has progressed from stage $R_{1/4}$ toward stage $R_{1/2}$ and assign a standard score that falls proportionately between the ones for each stage.

The difference between these procedures is negligible if the span of time between the attainment of the two stages is short. If, however, the stages are rather widely separated, e.g., 2.32 years for $R_{1/4}$ and $R_{1/2}$ in the permanent mandibular canine of boys, the experienced rater can usually improve the estimate of dental maturation by judging the degree of advancement from the stage just passed toward the next one.

Summary

The chronology of the formation of the permanent mandibular posterior ($C-M_3$) teeth and the later stages of the permanent maxillary and mandibular incisors was determined and presented in graphic form. The charts were designed specifically for determining the dental maturation of an individual child for each tooth separately.

The authors are indebted to Dr. Harold C. Stuart, Professor of Maternal and Child Health, Emeritus, for the use of data collected under his direction at the School of Public Health, Harvard University. The authors also thank Dr. L. W. Sontag, Director of the Fels Research Institute, for his permission to utilize the serial oblique-jaw radiographs of the Fels studies. This material was obtained by Dr. Arthur B. Lewis, Associate in Orthodontics at the Department of Human Growth and Genetics, and Dr. Stanley M. Garn, Chairman. To both Dr. Garn and Dr. Lewis, the authors express their gratitude.

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