The Consideration Of Dental Development In Serial Extraction

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The presence of crowding and spacing of the teeth has been expressed in a theoretical model as a function of three factors: tooth size, arch size, and the relation between tooth size and arch size in individuals[1]. This model is illustrated in Figure 1 reviewing the conditions that must be met for normal and abnormal tooth alignment.

A complete absence of either crowding or spacing [σ^2 (CS) $= 0$] is found when the variance of the combined mesiodistal crown diameters of the teeth and that of the size of the dental arch is identical [$\sigma^2 T = \sigma^2 A$] and when tooth and arch size are perfectly correlated (rTA $= 1$, Fig. 1A).

Crowding and spacing occur in spite of a perfect association between the size of the tooth crowns and the dental arch (rTA $= 1$), when the variance of tooth size becomes larger than that of arch size [$\sigma^2 T > \sigma^2 A$] as shown in Figure 1B.

Likewise, crowding and spacing result when the correlation between tooth size and arch size is imperfect (rTA < 1) while the variances of tooth size and arch size are similar [$\sigma^2 T = \sigma^2 A$,] Fig. 1C.

This last thesis was found to explain the incidence of crowding and spacing of the permanent mandibular dentitions of seventy-two students of Forsyth School of Dental Hygienists (Fig. 2). Accordingly, crowding may occur in individuals with less than average tooth size and also in individuals with more than average arch size.

In the analysis of the transitional dentition of the growing child, a difficult problem is encountered to predict the alignment of the permanent teeth because future increments in the size of the dental arches and the differences in crown size of the deciduous and permanent teeth must be considered. When, as a result of the clinical evaluation, the indication for serial extraction is established, an unfavorable prognosis is actually implied for a harmonious relation between arch size and tooth size in the permanent dentition.

Therapeutically, it is proposed to influence this unfavorable relation by reduction of tooth size, generally through extraction of the first premolars. The sequential program of serial extraction aims also at relieving the crowding of the permanent incisors by removing deciduous canines. Acceleration of the premolar eruption is obtained by extraction of its deciduous predecessor and extraction of the first premolars immediately following their emergence permitting self-alignment of the permanent canines.

To elucidate some aspects of the diagnostic dilemmas encountered when determining indication and timing of serial extraction, normative data of dental development will be reviewed. As such, this report constitutes an indirect approach to a problem that is generally discussed by citing actual

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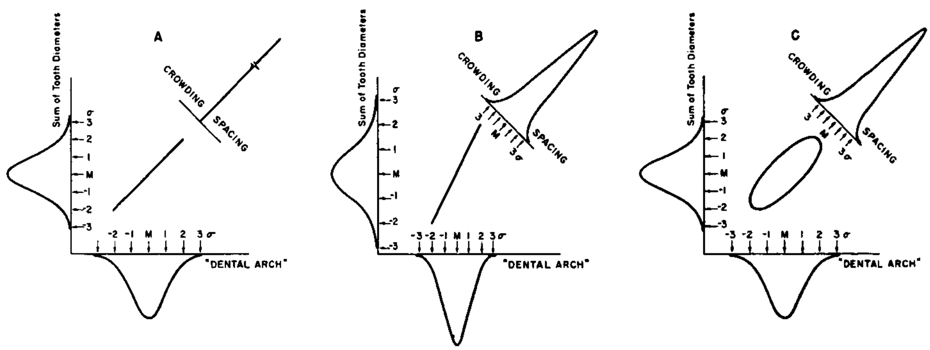

Fig. 1 A theoretical model for the analysis of the variance of spacing and crowding of the teeth as a function of tooth size, arch size, and the relation between tooth size and arch size in individuals.
A. No crowding or spacing of the teeth: $\sigma^2T = \sigma^2A$; rTA = 1
B. Crowding and spacing of the teeth: $\sigma^2T > \sigma^2A$; rTA = 1
C. Crowding and spacing of the teeth: $\sigma^2T = \sigma^2A$; rTA < 1
These three figures are based on mathematical computations.

experiences from clinical practice.

Materials

The data of this report have been obtained from three longitudinal and one cross-sectional studies. While the latter was collected at the Forsyth Dental Infirmary, the longitudinal material was generously made available to Forsyth by Dr. Harold C. Stuart, Professor of Maternal and Child Health, Harvard University; by Dr. Richard H. Stucklen of West Chester, Pennsylvania; and by Dr. Stanley M. Garn, Professor of Physical Anthropology and Chairman of the Department of Growth and Genetics of the Fels Research Institute, Yellow Springs, Ohio.

For determining mesiodistal crown diameters of the deciduous and permanent teeth as well as the changes in the dimensions of the dental arches, use was made of the dental casts from the longitudinal studies conducted by Dr. Harold C. Stuart[2,3] at the School of Public Health, Harvard University and by Dr. Richard H. Stucklen at the Bayard School in Wilmington, Delaware. These two sources contributed serial dental casts of 184 North American White children. No more than one third of this total has been used, excluding, out of necessity, for various aspects of the study those with mutilated permanent dentitions, missing records of the deciduous dentition or malocclusion of the permanent dentition, as reported already in detail[4].

Norms of root formation of the permanent mandibular canines and premolars pertain to a sample of approximately 246 North American White individuals, 136 males and 110 females. This sample of Ohio-born children was selected and studied by Dr. Elizabeth A. Fanning[5] from the extensive series of oblique or lateral jaw radiographs collected semiannually by Dr. Arthur B. Lewis at the Fels Research Institute.

The variations among individuals in the root length of their permanent teeth at the time of clinical emergence were determined for the maxillary incisors and all mandibular teeth except third molars.

Dr. Anna-Marie Grøn collected dental radiographs of 874 Bostonian children principally patients of Forsyth's clinics, supplemented by pupils of two public schools in Waltham, Mass. Of specific concern are the data[6] for permanent mandibular canines and premolars.

Methods

There is a general agreement in the technique of measuring mesiodistal crown diameters of the teeth[4,7] as well as in the magnitude of differences resulting from double determinations by two investigators[4,8]. The same conclusion applies to the quantitative expression of the lack, or surplus, of space for the teeth in the dental arch[4,9].

Landmarks for determining arch dimensions differ among investigators depending on the objective of their study[7]. The definitions of arch length, breadth, and circumference are only shown graphically (Fig. 3) since a detailed account of measuring arch size has been reported already[4].

Root formation is determined by comparing intermediate stages to the com-

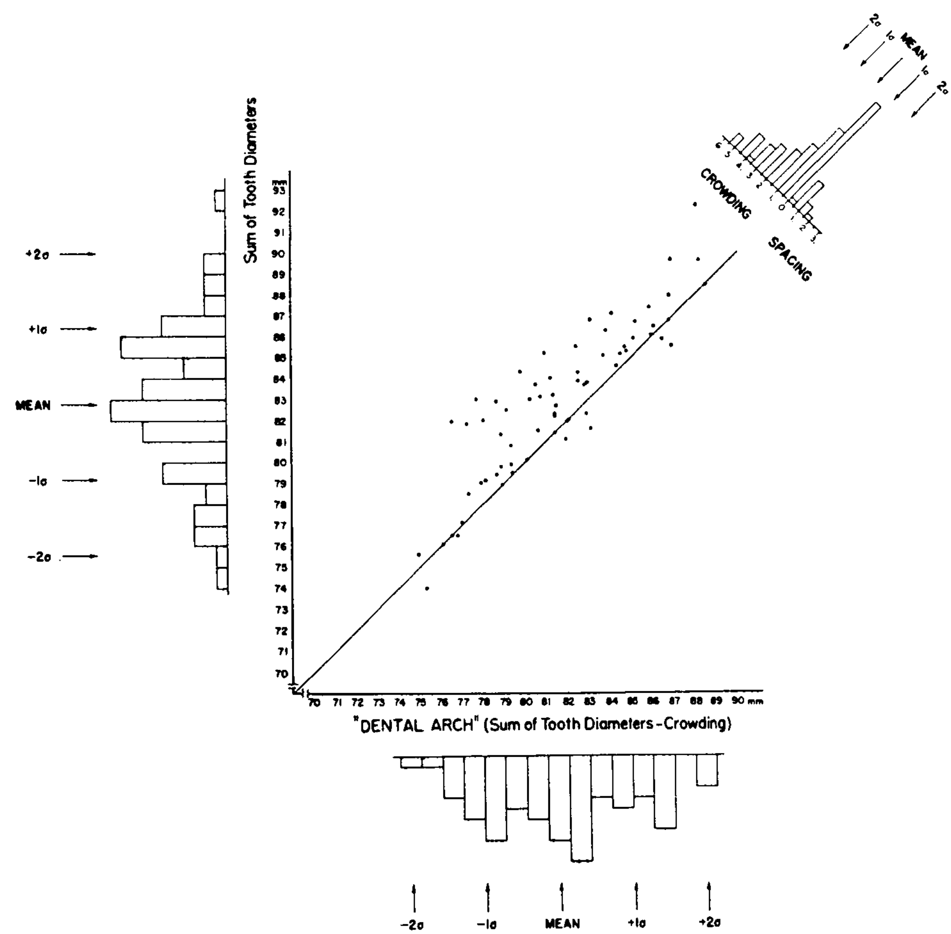

Fig. 2 Biometric analysis of crowding and spacing in the mandibular dentitions of seventy-two females. Note: Dots above the diagonal line represent dentitions with crowding, those below the line dentitions with spacing and dots on the diagonal line indicate perfect harmony between tooth size and arch size.

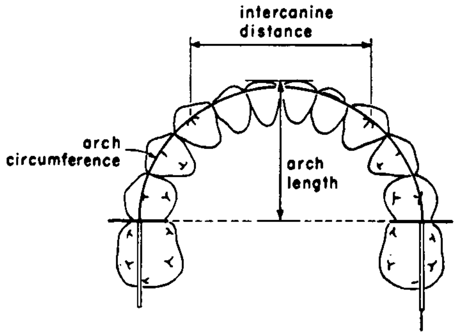

Fig. 3 Methods of measuring arch length, the intercanine distance and arch circumference.

pleted root length when serial radiographs of an individual are available. In cross-sectional material the fraction of mature root length that a tooth has attained must be estimated with reference to the roots and alveolar outlines of adjacent teeth without having recourse to the radiograph of the completed tooth.

Root development of the permanent canines and premolars is generally determined by segmenting the continuous process of root formation in quarter stages as shown diagrammatically in Figure 4. The number of stages for

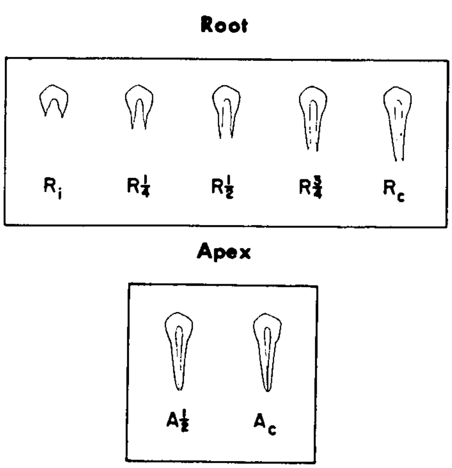

Fig. 4 Stages of root formation for determining dental maturation.

rating root length is limited for clear differentiation between successive stages, particularly when serial data are lacking as is usually the case in clinical practice.

The extent of root formation can be defined either by the approximate attainment of a stage, such as one quarter root length ($\pm\frac{1}{4}$), or at an intermediate level between two stages when, for instance, more than one quarter but less than one half of a root is formed ($\frac{1}{4}$ - $\frac{1}{2}$). This subclassification has an important bearing on the interpretation of the normative data for the timing of serial extraction procedures.

Findings

Dental Development

First Phase.—At the time that serial extraction is considered to relieve crowding of permanent incisors, the first phase of dental development is nearly completed. During the eruption of the permanent incisors both arch length and breadth have increased. The average increment in the length of the dental arch is approximately one mm in the maxilla and even less in the mandible (Fig. 5).

The increment in arch breadth, expressed by the maxillary and mandibular intercanine distances, is approximately three mm in both jaws during the incisor transition of the average child of either sex (Fig. 6).

In individuals the changes in arch breadth and arch length are subject to marked variations and, similarly, the beginning and ending of the increments in arch breadth may differ considerably from those suggested by the average trends.

The mean difference between the combined mesiodistal crown diameters of the four deciduous and permanent maxillary incisors is 7.4 mm in males and 6.7 mm in females. These figures

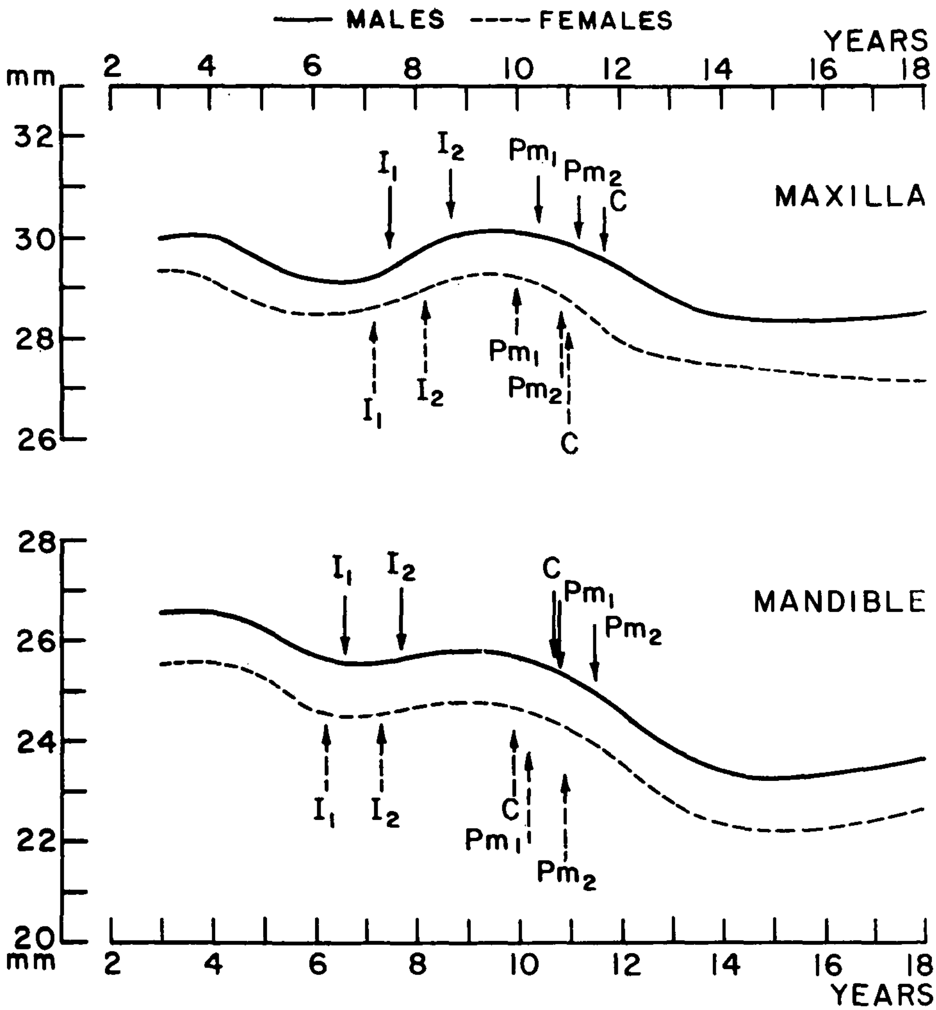

Fig. 5 The average arch lengths at various ages in the maxillary and mandibular dentitions of males (solid lines) and females (broken lines). The arrows refer to the mean ages of emergence of the permanent teeth (Hurme[15]).

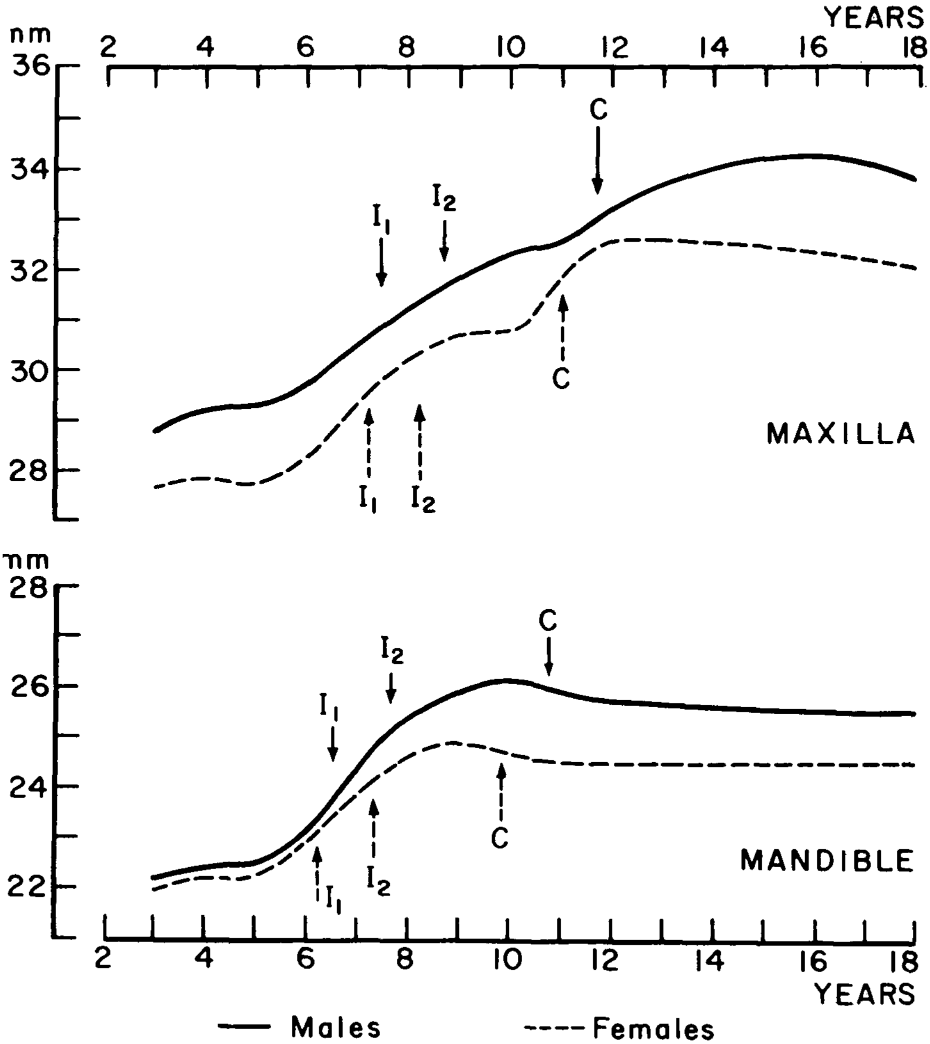

Fig. 6 The average distances between the maxillary and mandibular canines at various ages in males (solid lines) and females (broken lines). The arrows refer to the mean ages of emergence of the permanent incisors and canines (Hurme[15]).

TABLE 1

Differences in mesiodistal crown diameters of corresponding tooth groups in the deciduous and permanent dentitions*.

Teeth	Sex	Mean (mm)	S.E.M (mm)	S.D. (mm)	Range (mm)	Number
			Incisors			
Maxillary	M	—3.71	0.13	1.00	—0.2 to —5.8	62
	F	—3.33	0.10	0.77	—0.8 to —5.0	58
Mandibular	M	—2.57	0.09	0.69	—1.2 to —4.4	58
	F	—2.57	0.08	0.66	—0.9 to —3.9	61
		Canines and deciduous molars (premolars)				
Maxillary	M	+1.20	0.11	0.90	—1.1 to +3.1	62
	F	+1.46	0.12	0.94	—0.5 to +3.6	58
Mandibular	M	+2.16	0.12	0.92	—0.1 to +4.2	58
	F	+2.59	0.11	0.85	+0.7 to +4.7	61

* A plus sign infers that permanent teeth < deciduous teeth; a negative sign that permanent teeth > deciduous teeth.

are obtained by doubling the findings[10] based on averages of left and right teeth, shown in Table 1. In the mandible the mean difference between the crown diameters of the four incisors is the same in both sexes, namely, 5.1 mm.

As a result of the changes in the dental arch dimensions and the presence of interdental spaces between the deciduous incisors, averaging 3.0 mm in the maxilla and 1.5 mm in the mandible, a sufficient amount of space is available for the alignment of the permanent maxillary incisors of the average boy and girl, but their mandibular incisors are slightly crowded.

More important are the marked individual variations at 8-10 years of age in the available space of the incisor segment[4] during the incisor transition of children with "normal" permanent dentitions at age 18 (Figs. 7 and 8). These variations are in two directions, but a lack of space during the incisor transition occurred in one half of the children studied, according to the symmetrically distributed observations.

The amount of crowding at the lowest limit of the two standard deviation curve would justify consideration of serial extraction except that normal occlusion was achieved without any therapy in all children of this sample. These normative data should not be interpreted to imply that every child will have a normal occlusion at eighteen years of age simply because the available space in the incisor segment is within the plus and minus two standard deviation limits during the eruption of the incisors.

Second Phase.—The eruption of the premolars and canine initiates the second phase of dental development. At this time the average intercanine distance increases about two mm in the maxillary dentition in either sex and it decreases slightly in the mandible (Fig. 6). A review of individual records of dental development and the statistics describing the spread of observations in the sample studied indicate that the increments in the intercanine distances are highly variable[4].

During the premolar emergence the

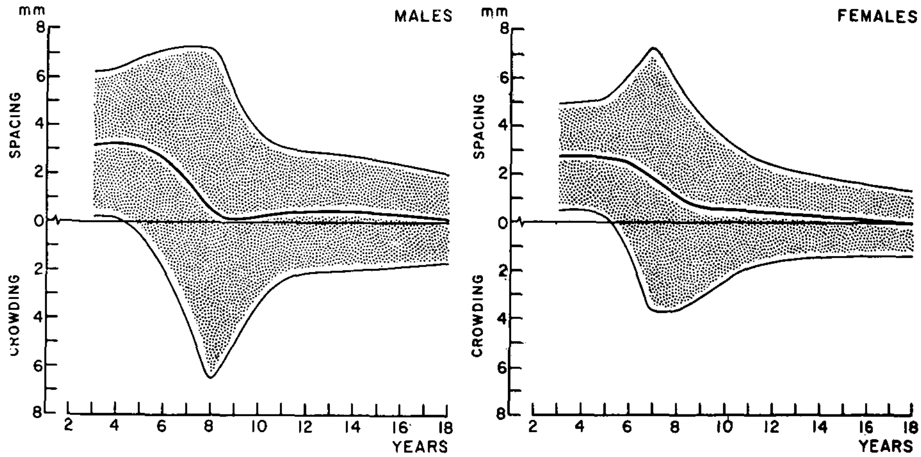

Fig. 7 The available space (Mean ± 2 S.D.) in the maxillary incisor segment at various ages in males and females.

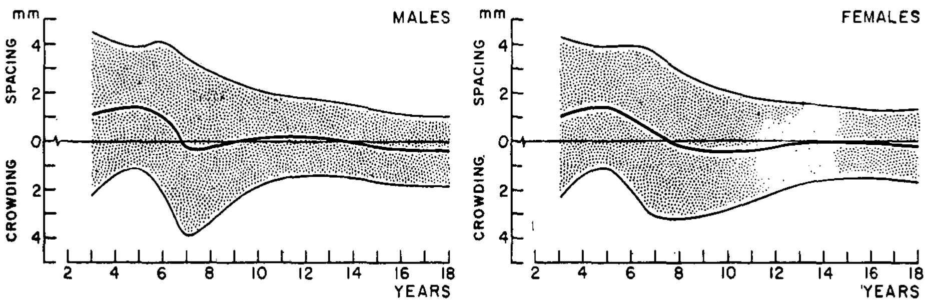

Fig. 8 The available space (Mean ± 2 S.D.) in the mandibular incisor segment at various ages in males and females.

mean arch length decreases in both jaws of both sexes (Fig. 5), but particularly in the mandible as a result of mesial drift of the permanent first molars and the uprighting of the incisors[11].

The replacement of the deciduous molars by their permanent successors contributes space for tooth alignment, the so-called *leeway* space. Part of this space is taken up by migration of the permanent molars depending on the sequence of shedding and emergence of the deciduous second molars and the second premolars, respectively, the position of second premolars in relation to the mesial aspect of permanent first molars, as well as on the interdigitation of the cusps of the first molars. When neutroclusion has been established prior to the loss of the deciduous second molars and when these teeth are shed in a favorable sequence, less migration of the permanent molars occurs than in the case of cusp to cusp occlusion combined with simultaneous loss of all four deciduous second molars.

In spite of the proportionately large crown diameter of the permanent canine the percentage ratio of the combined crown diameters of the three posterior deciduous teeth and their permanent successors is greater than 100, signifying that three deciduous teeth exceed the three permanent ones in size.

TABLE 2

Combined mesiodistal crown diameters of deciduous incisors as well as deciduous canines and molars expressed as a percentage of those of their permanent successors.

Teeth	Sex	Mean (percent)	S.E.M (percent)	S.D. (percent)	Number
		Incisors			
Maxillary	M	76.7	0.71	5.6	62
	F	77.9	0.58	4.4	58
Mandibular	M	77.4	0.71	5.4	58
	F	77.9	0.88	6.9	61
		Canines and deciduous molars (premolars)			
Maxillary	M	105.4	0.57	4.5	62
	F	107.1	0.60	4.6	58
Mandibular	M	110.1	0.59	4.5	58
	F	112.9	0.59	4.6	61

especially in the mandible (Table 2).

The individual variations in this ratio, and likewise in the absolute differences, are marked according to the standard deviations. They are also well illustrated by the ranges shown in Table 1 for averages of left and right teeth resulting in as much as 3.1 to 4.7 mm space during the canine-premolar transition in maxilla and mandible, respectively. In contrast, the permanent canine and premolars can be larger (—0.5 and —1.1 mm) than their deciduous predecessors in the maxilla of both sexes and in the mandible they may be of the same size (Table 1). These data establish clearly that the replacement of deciduous canines and molars may affect the crowding of the incisors, if still persisting, to varying degrees in either a negative or a positive sense.

Clinical Evaluation of Dental Development.—The relation of deciduous and permanent teeth ($dc + dm_1 + dm_2 : C + Pm_1 + Pm_2$) can be determined rather accurately, prior to the emergence of the permanent teeth, by measuring mesiodistal crown diameters of the deciduous teeth on dental casts and those of the permanent teeth in dental radiographs. However, the prediction of the changes in arch breadth

TABLE 3

Correlation coefficients for the intercanine distance at 4-5 or 9 years and at 16-18 years.

Age range	Males r	Males S.E. r	Number	Females r	Females S.E. r	Number
			Maxilla			
(4-5) to (16-18)	+0.45	±0.10	63	+0.48	±0.08	59
9 to (16-18)	+0.75	±0.07	37	+0.83	±0.06	32
			Mandible			
(4-5) to (16-18)	+0.48	±0.09	68	+0.46	±0.10	58
9 to (16-18)	+0.50	±0.12	37	+0.77	±0.07	30

is not accomplished as readily. Correlation coefficients for the intercanine distances show a moderate degree of association (ranging from +0.43 to +0.48) at 4-5 and 18 years and a significantly higher association, except for the male mandible, at 9 and 18 years (Table 3). The errors of estimate, also when predicting intercanine distance in the adult dentition from that at 9 years, are relatively high varying between 1.2 and 1.6 mm. At the 95 per cent level of confidence the actual size of the intercanine distance in the permanent dentition of an individual is within a range of plus and minus two times the error of estimate from the expected value.

As a practical solution the acquisition of periodic records is suggested. When longitudinal data are available, the past record may be of considerable value to reveal the velocity of the first growth phase and its ending.

The Timing of Serial Extraction

The development of the premolars and the permanent canine, assessed by studying the amount of their root formation from intraoral or, preferably, lateral jaw radiographs, affords an objective means to determine the timing of orthodontic treatment in the mixed dentition. A special chart was designed

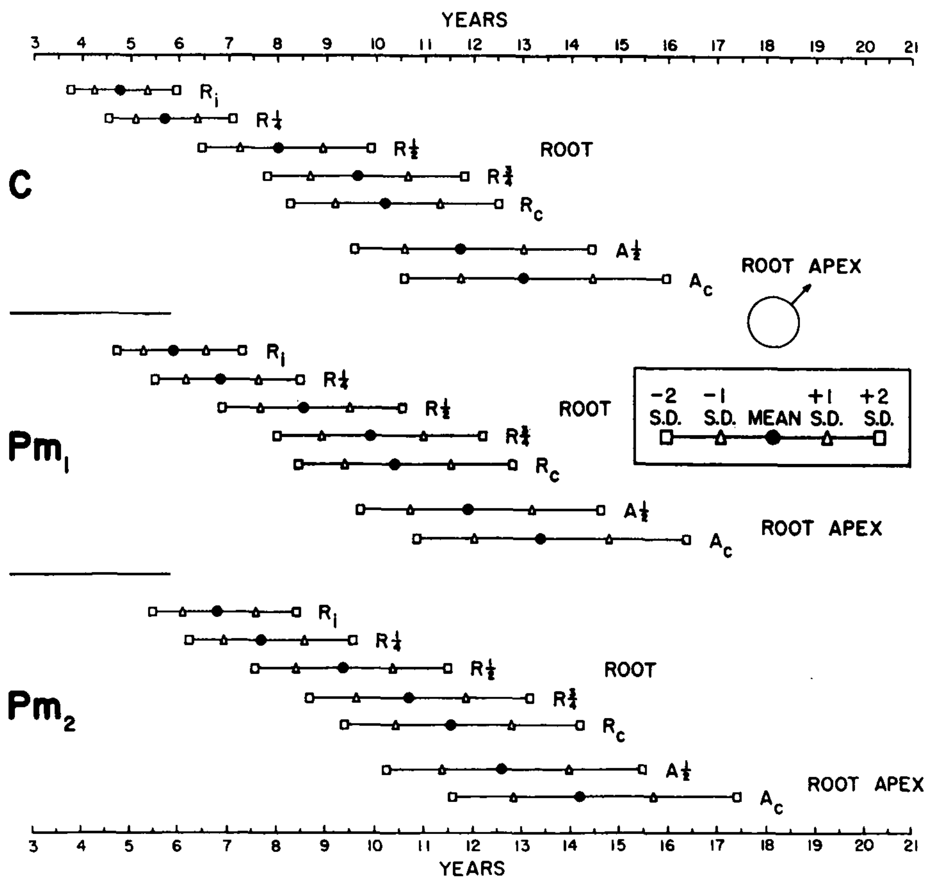

Fig. 9 Norms of root formation for the permanent mandibular canines and premolars of males.

for evaluating dental maturation from the data of Dr. Elizabeth A. Fanning[5].

The chart is composed of three parts, one for each tooth under consideration (C, Pm_1, and Pm_2), as shown in Figures 9 and 10 for males and females, respectively. The horizontal axes at the top and bottom represent age in years. In the component sections for each tooth, the mean age as well as the plus and minus two standard deviation limits for the attainment of various stages of root development from initial root formation to closure of the apex are presented graphically by horizontal bars.

A careful estimate is made of the length of the canine and premolar roots utilizing the developmental stages shown in Figure 4. A check mark is made on the chart at the appropriate stage attained by each tooth.

Dental maturation is read directly in standard scores at the intersection of the vertical age line and the horizontal bars that indicate the extent of root length for the teeth of the child studied.

When root length is intermediate between two stages, an interpolated rating is made (Fig. 11). For instance, if the development of a permanent canine in a 6.2-year-old girl is rated at the

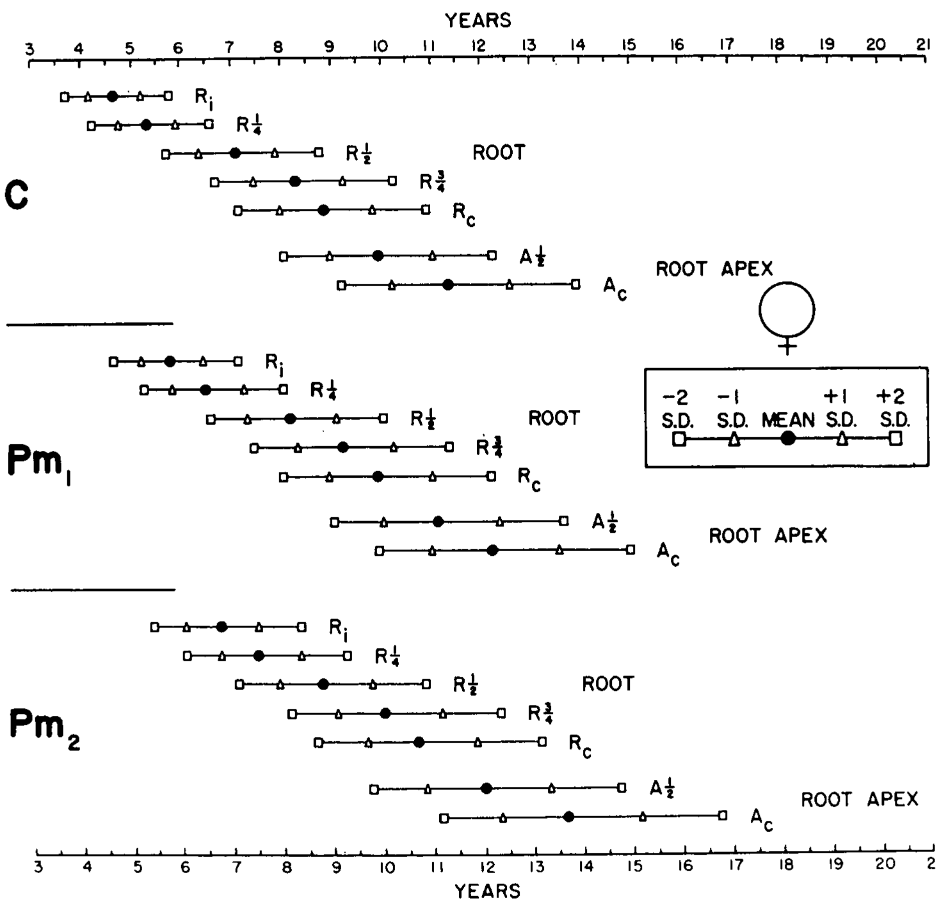

Fig. 10 Norms of root formation for the permanent mandibular canines and premolars of females,

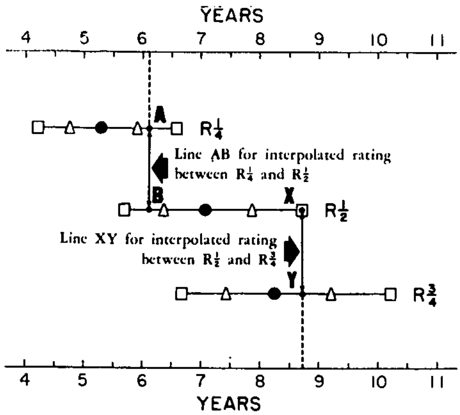

Fig. 11 The assessment of dental maturation in terms of the norms when canine root length is intermediate between stages. Two hypothetical instances are shown in a section of the norm chart of females, one girl being 6.2 and another 8.75 years old.

quarter root stage, its development is approximately 1.3 standard score late. However, when more than one quarter but less than one half of the canine root length has been formed, the standard score values for the two stages that determine the interpolation limits are averaged, *in casu*: R¼ = +1.3 standard score and R½ = —1.5 standard score. The evaluation is computed by summation of the standard score values divided by two, namely: $\frac{+1.3. - 1.5}{2}$ = —0.10 standard score. This finding constitutes an insignificant deviation from the mean, the child being neither advanced or retarded in the development of the canine.

The interpolation can also be weighted if warranted by the interpretation of radiographs if, for example, a canine root is considered to be very close but not quite at the three-quarter achievement of its length in an 8.75-year-old girl (Fig. 11). The rating at the R¾ stage (+0.5 standard score) is given 3 (or X) times more weight than that at the preceding (R½) level (+2.0 standard score) as follows:

$$\frac{(1 \times 2.0 \text{ st. sc.}) + (3 \times 0.5 \text{ st. sc.})}{4}$$

$$= +\,0.875 \text{ standard score.}$$

Interpolation halfway between two stages is preferable in most instances because it is frequently impossible to determine the exact root length from radiographs.

The deviation from the mean may be expressed also in years except that the significance of a time period differs greatly between the early and late stages of root formation. At initial root formation, one half year equals one standard deviation and at the completed root stage, only one-half standard deviation.

To make the best use of the assessment of root development with specific reference to serial extraction procedures, an effort has been made also to determine root length at clinical emergence of the tooth crown. The findings for the permanent mandibular canines and premolars are presented in Figure 12 utilizing the data obtained by Dr. Anna-Marie Grøn[6] from samples of 50 (± 2) children of each sex for mandibular canines and premolars at emergence (< 3 mm). Excluded were individuals with lack of space for the emerging tooth and those with history or evidence of early loss of the deciduous predecessor.

In general, three quarters of the root length is attained when the teeth emerge, but the canine tends to have a proportionately longer root when it pierces the gingival tissues than the premolars. Formation of less than one quarter of the root or a closing apex were not observed. Sex differences in the amount of root formation at emergence are not statistically significant although the development of the canine roots of females exceeds that of males.

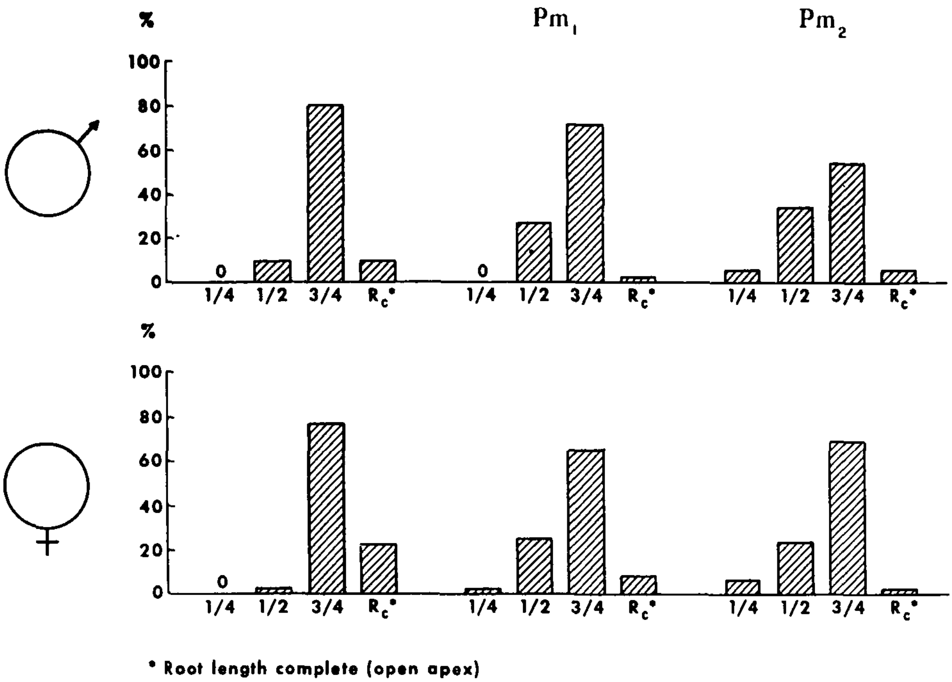

Fig. 12 The extent of root formation at emergence.

In view of the variation among individuals in the amount of root formation at clinical emergence it is not possible to predict the exact time of emergence from root length, even when also considering the skeletal age as an additional measure of physiologic age. However, the findings infer that deciduous molars should not be extracted before at least one quarter of the premolar root length has been attained if close to *alveolar* emergence and otherwise one half root development.

The deciduous canines, depending on the position of their permanent successors in the mandible and also on their inclination, should not be removed before the permanént canine has attained one-half of its root length unless the first premolar is about to emerge.

The time needed for the formation of roots of the canines and premolars[13] is also relevant for determining the timing and sequence of serial extraction in clinical practice (Fig. 13). The mean time interval between attainment of ¼ to ½ root length is 2.3 and 1.8 years for the permanent canines in males and females, respectively, and 1.7 years for the premolar in both sexes. The average time for the formation of the next quarter root (½ to ¾) is less, ranging from 1.6 to 1.1 years.

The last quarter of the full root length, the apex remaining open, is formed in one half to two thirds of a year except for the second premolars of boys (0.9 years). This finding confirms the observation of Gleiser and Hunt[14] for permanent mandibular first molars that a relatively rapid elongation of the root occurs at, or soon after, clinical emergence.

These mean time intervals only offer measures of central tendency. Accordingly, it must be expected that root de-

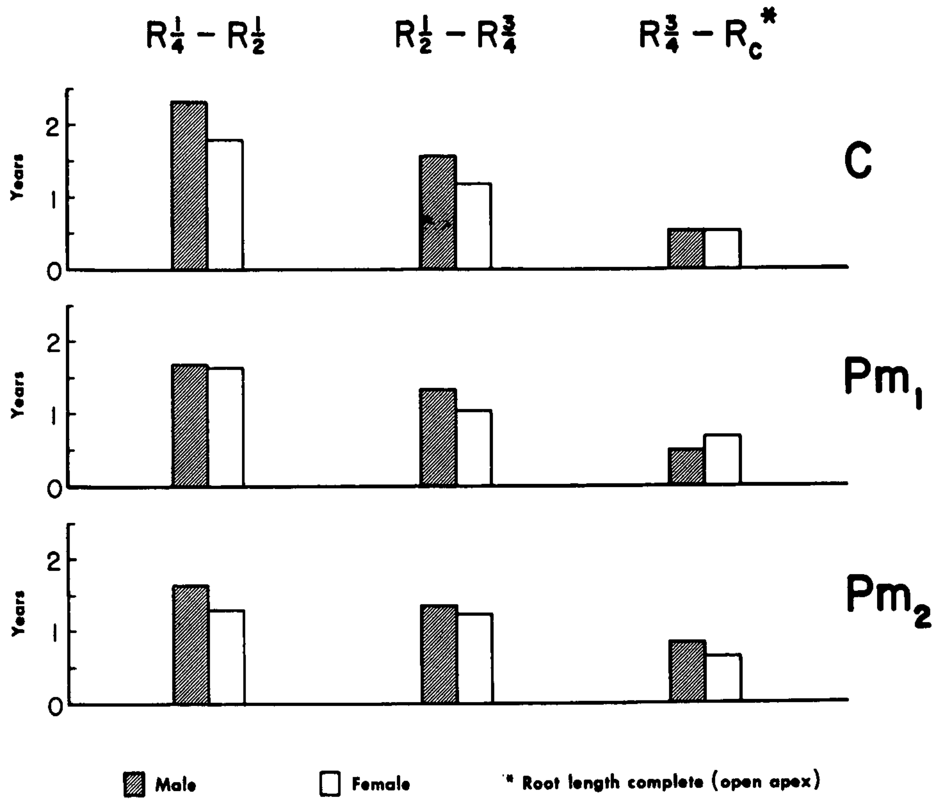

Fig. 13 The average time for the development of quarter stages of root length.

velopment is speedier in some children and slower in others, compared with the increments in the root length of the average child. In the absence of statistics refining the extent of individual variation in increments of root length, the repeated observation of a child offers the only clue to estimate the velocity of its tooth formation. Therefore, the periodic recording of root formation on the chart is recommended.

The optimal time for extraction therapy can be estimated also by directly predicting the time needed for reaching the ½ or ¾ root length level, when emergence generally occurs, from the rating of root development at the time of examination and the mean time interval between stages (Fig. 13). Interpolations can be used in the computations when root length is intermediate between two stages. This prediction is subject to error that may be critical in fast growing roots, principally because of unavoidable inaccuracy to determine root length exactly and because of the use of mean time intervals. When radiographs are obtained routinely, as suggested, root length and the velocity of its development for the individual can be determined more precisely, resulting in better definition of the timing of serial extraction procedures.

When root development of premolars and canines is evaluated, it becomes doubtful if serial extraction should be initiated immediately after eruption of the lateral incisors in a malaligned position. Postponing treatment allows reevaluation of the indication for serial extraction if changes in the dental arches occurred. Another advantage is shortening of treatment time since therapy cannot be completed before full eruption of the second premolar.

A change from the classical sequence (dc, dm_1, Pm_1) of serial extraction[12] should be considered also to prevent a spurt in the eruption of the permanent canine that may lead to impaction of the first premolars, especially in the mandible of females[13]. Depending on the inclination and position of the unerupted permanent teeth relative to each other and to the alveolar margin, extraction of the deciduous first molars should be performed first. The first premolars are extracted after emergence together with the deciduous canines, when still present.

In summary, the findings from our studies of dental development emphasize the need for routine longitudinal observation of patients as part of child care in pedodontic practice to facilitate orthodontic diagnosis at a later age. The most suitable developmental levels for observation are as follows:

1. The deciduous dentition, just before the emergence of the permanent mandibular central incisors,

2. Shortly after the emergence of the permanent maxillary central incisors,

3. After the emergence of the permanent maxillary lateral incisors.

An analysis of the changing dimensions of the dental arches, mesiodistal crown diameters of the deciduous and permanent teeth, the position and inclination of unerupted permanent teeth relative to the alveolar margin and to their neighbors, as well as the use of a biologic age scale on the basis of tooth formation, is recommended to define the indication, timing, and sequence of serial extraction procedures.

Conclusions

The indication of serial extraction depends on growth changes of the dental arches and on the so-called leeway space or the difference between the combined mesiodistal crown diameters of deciduous canines and molars and those of their permanent successors. While the latter can be determined relatively accurately by measuring tooth size on dental casts and in radiographs, the prediction of increments in arch size constitutes a most baffling aspect of clinical evaluation.

The occurrence of marked variations among individuals in the changes of arch size and in the leeway space explains a favorable or an unfavorable outcome of dental development, regardless of the amount of crowding in the incisor segment in the transitional period.

The timing of serial extraction should be based on root development that may be advanced or retarded relative to that expected from chronologic age. Norms of tooth development prove useful for determining an optimal age for extraction since teeth generally emerge when one half to three quarters of their mature root length has been achieved, canines having proportionately longer roots than premolars at emergence. In this connection the considerable length of time needed for root formation should be taken into account for treatment planning.

The sequence of serial extraction can be varied advantageously from dc, dm_1, Pm_1, to dm_1, (Pm_1 / dc,) depending on the respective positions of the developing permanent teeth to the alveolar margin and on their inclination to prevent impaction of the first premolar negating the principal objective of the method.

The data of longitudinal studies of

dental development point in general to a conservative attitude in instituting serial extraction procedures.

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