DENTAL DEVELOPMENTAL AGE VERSUS CHRONOLOGICAL AGE AS PREDICTORS OF CHILDREN'S FUNCTIONING IN FIVE DEVELOPMENTAL SKILLS AREAS

by

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This thesis is dedicated to my wife, Sandy, without whom neither dental school nor graduate training would have been possible. Her sacrifices, encouragement, understanding, and assistance could not have been greater.

The author wishes to acknowledge the direction and guidance of Drs. Ralph E. McDonald and Paul Starkey for their part in structuring an excellent Graduate Pedodontic Program.

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Finally, acknowledgment must go to my colleagues, Drs. Alvin Ayers, Clifton Dummett, David Kennedy, and Roberto Vianna who have, to say the least, made these last two years very interesting, enjoyable, and enlightening.

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INTRODUCTION

To provide good dental experiences for child patients, the dentist needs to understand child development as a basis for determining the techniques required to direct behavior management. The question then arises as to what criteria should be used to evaluate the child's overall development. Doubts have been expressed about the value of chronologic age as a guide to expected child development and behavior. McDonald[1] in his text on Pedodontics states that the chronological age of the patient is not nearly as important as the developmental age. According to Ilg and Ames[2] and many other authors, the child's behavioral level may be above or below his age in years and months. What we want to know about the child is his complete developmental level. We are concerned with the total individual, the intellectual and physical, as well as the behavioral aspects of the child. According to Lampshire,[3] no one type of development, such as the social aspects of the child, takes place apart from development in other areas, such as physical, mental and emotional status, and overall personality.

Since psychologists[4] have provided instruments for evaluating the developmental ages of the child (i.e. physical age, self-help age, communication age, social age, and academic age), it seems plausible that these ages could be used to correlate the child's developmental age with still another area of development, namely his dental developmental age. The purpose of this study is to determine whether the dentist, after clinical and radiographic examination of a child's dentition have shown that the child is either ahead or behind normal dental developmental patterns, might draw some conclusions from this about other aspects of the child's developmental age and therefore about the child's expected behavior. This study will test the relationship between dental developmental age and other aspects of the child's development.

Many methods have been used to determine readiness for school. Before compulsory school attendance was legislated, it really did not matter whether the child was 5, 5½, or 6 years of age. Classes were small and the children were allowed to progress at their own pace. At one time in our country's history, according to Ilg and Ames,[5] the criteria for school entrance into first grade were that the child had to be six years old and that the first permanent molars had to have erupted. As the number of children and the sizes of the classes increased, chronologic age became the sole criterion for school entrance. The main problem in using age as a basis for entrance is that even if we could accurately determine the best average age for first grade, "any average would still imply that only 50 per cent of any group of children might be expected to fall close enough to this average to ensure their reasonable readiness for school."[5] Thus, there would be 50 per cent exceptions to this average.

Research shows that the older child is more prepared for school than the younger.[5] However, this does not allow for the fact that the development of boys at primary ages is generally slower than that of girls in all phases. Also, in many areas the I.Q. is still the all-important measurement of the child's ability. Thus, in many communities a child with a high I.Q. is allowed to begin school early. It is apparent, however, that I.Q. is a measure neither of the child's physical nor behavioral maturity. This again raises the question of evaluating the child's complete developmental level.

Many authors believe that relating function to structure may be the answer. Ilg and Ames[5] state, "More often than not, physical immaturity, such as slow teething, goes along with behavioral immaturity." Similarly, physical maturity may go along with behavioral maturity. These authors feel that structure gives important clues to the overall development of the child and ask, for example, whether the eruption of the lateral upper incisors before the central incisors might imply difficulty or delay in focal central behavior. They suggest that the teacher might expect a little slower progress from the child.

In like manner, the pedodontist should not expect maturity where it is not yet developed. Ilg and Ames give two further examples. One eight-year-old boy was having trouble in the third grade and still had his four primary central incisors. Since he was teething below a six and a half year old level, it seems reasonable to question whether this boy was even capable of doing second grade work. Another eight-year-old third grader whom they examined had partial delay in eruption. The right central and lateral incisors were erupted but the left primary incisors had not exfoliated. Ilg and Ames suggest that this might alert the educator to the potential for marked discrepancy in behavior. One of their studies using eruption patterns as a variable showed that 64 per cent of those children with delayed eruption were either repeating or would have benefited by repeating grades. However, 36 per cent of those with delayed eruptions were doing nicely and were described as hard workers. While this might show that school placement, for example, cannot be judged by one variable, Ilg and Ames state that tooth eruption findings can support and sometimes clarify other evidence of physical and behavioral growth.

Though many relationships may be found, children should not be placed in rigid categories. Massler[6] states, "A robust, vivacious child erupts his teeth at an earlier age than a less active brother" but we must be careful not to interpret that statement as a principle and thus characterize all robust, vivacious children in relation to their dentition. Children mature at different rates and reach pubescence at different chronological ages. Thus, we may assume that they also reach different levels of behavioral maturity at various chronologic ages. Perhaps the most important point, as Jones and Bayley[7] stated, is that many factors, psychological and cultural as well as physical, contribute to the formation of basic personality patterns.

On the basis of all these ideas, it seems reasonable to search for a better way than chronologic age to judge the development of the child. It is from this proposal that the hypothesis of this thesis has been developed: that the dental developmental age of the child may be a better predictor of the various areas of development of the child than is his chronologic age.

REVIEW OF LITERATURE

This review will deal first with the relationships between tooth eruption and/or calcification and other aspects of the child's physical maturation, and then with the practicability and validity of using panoramic radiography for estimating dental development and thus dental age.

Relationships Between Dental Age and Other Developmental Aspects

Though a number of authors have dealt with the developmental relationship between dentition and somatic, mental, and emotional maturation, opinions differ as to the relationship. Several studies show close relationships while others show none. An early reference to how physical characteristics and age may be related to other developmental indices was by Beik[8] in 1913. He felt that the dentition was a good indication of the stage of progress that the child had reached in his total physical development. "Since there is a close correlation between mental and physical development, should not qualifications for school entrance be the emergence of the first permanent molar...don't burden the child before this." Thus, his requirement for entrance to school would be based on the measurement of physical age which he concluded was far superior to chronologic age.

In 1926 Perkins[9] studied 555 maladjusted children by means of a Stanford-Binet evaluation and a tooth examination. He found that eruption of permanent teeth more nearly paralleled chronologic age than mental age. In 1928 Cattell[10] refers both to Bean (1914) and Mateigka (1921) in supporting use of the dentition and its eruption in obtaining precise indications for evaluating physical development. Cattell also refers to Bean, Mateigka, Woodrow, Abernathy, and Perkins as reporting a low but positive correlation between dentition and Binet mental age, with chronologic age being held as a constant of $(+.47 \pm .02)$. On the other hand, Cattell found correlations between mental age and physical age that were higher than between mental age and dentition.

By the 1940's many authors were reporting that early and late physical maturers were respectively early and late in "overall" physical development. In 1945 Steggerda[11] reported a low but definite statistical correlation between accelerated and retarded dentition and the child's height and weight. This was confirmed by Talmers[12] in 1952 and Pittorru[13] in 1956. Previous to this time, dentition had been evaluated on the basis of whether or not the tooth had emerged or "pierced the gum." The discussion section will deal with the validity of this method of evaluation. In

1951 Moorrees and Garn[14] suggested that early or late tooth eruption may be due to environmental factors or may have a racial basis, since they found that emergence was later in Caucasians than in Negroids and Mongoloids. Steggerda[11] also reported later emergence in Caucasians than in Negroid and Navajo children.

Many authors have chosen one single tooth to study relationships between chronologic age, skeletal age, and dental development. Demisch and Wartmann[15] in 1956 found a correlation coefficient between third molar calcification and skeletal age, with chronologic age held constant to be .45 in both males and females. They felt that this supported the existence of a relationship between the maturation of various tissue systems. From this, they postulated that one might be able to estimate skeletal age indirectly if the calcification of other teeth is taken into account.

In 1958 Voors and Metselaar[16] studied the reliability of dental age as a yardstick to assess unknown calendar age. They used 2400 children, birth to 15 years old. In examining the upper left quadrant only, they concluded that if calendar age is not known, dental age is a reliable characteristic for identifying different age groups in children.

In 1958 Lammons and Gray[17] reported an investigation of the relationship between skeletal, dental, and chronological age. They studied 25 males and 36 females with an age range from 4 to 15 years in a longitudinal investigation. They used the charts of Massler and Schour to assess dental age and found that chronologic age is a better index of tooth development than is skeletal age. They further noted that skeletal and dental age may vary independently.

Another interesting study in the maturation of various developmental aspects of the child was done by Binning[18] in 1958. He found that among large groups of children between the ages of 6 and 15 years the "faster" growing ones (when chronologic age is held constant) had higher I.Q.'s.

Garn and Lewis[19] in 1958 and Steel[20] in 1965 discussed a survey of permanent mandibular first molars made in 1955 by Gleiser and Hunt.[21] Garn and Lewis stated that "on an individual basis the calcification of a tooth may be a more meaningful indication of somatic maturation than its clinical emergence." They found that females were ahead not only in eruption but also in tooth calcification. The smallest differences occurred early in life, with more divergence occurring steadily as the child matures. Since females were considerably ahead prior to the age of 10 years, the difference could not be attributed to the time of secretion of the sex hormones.

Bambha[22] in 1959 said that there was no evidence of association between the time of tooth eruption and the time of skeletal maturation. In the same year, Bayer and Bayley[23] compared standard wrist plates (via Greulich and Pyle) and reported that at best skeletal age will fall one year above or below chronological age in two-thirds of the population. Thus, a spread of two years was probable in examining any wrist plate. They also stated that the stage of maturation tends to be closely associated with behavioral as well as physical aspects of development.

Hotz[24,25] in 1959 drew two important conclusions on the relation of dental calcification to chronologic age and skeletal age. A total of 148 males and 150 females were examined between the ages of 6 and 11 years. On the basis of 11 stages of calcification, Hotz found that (1) intra-alveolar calcification by analogous teeth was found to be symmetrical and that the difference between examiners was rare and never exceeded more than one stage, and (2) that there was a greater degree of association between dental age and chronologic age than between dental age and skeletal age. The correlation factor he found was 0.8.

Garn and Lewis[26] reported in 1960 that throughout infancy and childhood there was a low positive correlation between tooth formation and the five criteria above (for instance, the correlation of tooth formation and bone age was +0.274 at the 0.05% significance level), but that the correlation between tooth formation (measured on an oblique radiograph using five stages of eruption and formation) and menarchy often was as high as +0.62.

Nolla[27] in 1960 analyzed annual serial radiographs on 25 females and 25 males. The development of each tooth was evaluated on a scale of 0 to 10. The conclusions were: (1) that the type of growth displayed by each tooth was the same, (2) that there was no significant difference in the rate of development in females as opposed to males though females started earlier and finished earlier in dental development, and (3) that there was no significant developmental variance from one side of the jaw to the other.

In 1960 Sjunnesson[28] reported an investigation in which 392 children were examined in special education classes for low ability and 400 children chosen at random were used as a control group. He found no difference in the rate or number of erupted permanent teeth between the two groups.

Lauterstein[29] in 1961 reported a higher positive correlation between chronologic age and root age than between chronologic age and bone age.

Zannini,[30] who studied the relationship of dental eruption to thoracic size, weight of body, and height in 1200 subjects, found that people with greater measurements in those three areas had a greater number of permanent teeth erupted when age was held at a constant. He concluded that the morphology of the individual is related to the chronology of the eruption of permanent teeth.

In 1964 Skubiszewska[31] recorded the amount of calcification and the amount of eruption in 273 subjects, 7 to

14 years old. He gave points for seven stages of development and used the sum of these points to equal dental age. He compared those data to the child's skeletal age, evaluated by using hand and elbow radiographs. Two conclusions were drawn: (1) that sex differences are less significant in dental development than in skeletal development, and (2) that sex differences in the maturation of the skeletal system are more pronounced than in the formation of teeth.

Gibson et al[32] in the same year reported a correlation between somatic development, bone age, and eruption, but on the basis of only two subjects: a very large and a very small male. He felt that dental development is closely related to the total development of the child.

Achesons and Fowler[33] studied 122 families from various socioeconomic levels to examine the influence of environment on growth and development. They found that skeletal maturation was much less affected by socioeconomic levels than is growth, that males in higher socioeconomic level groups grew faster, and that their predicted height was greater, but that there was no specific difference in the rate of skeletal maturation. They also reported that rates of maturation for females did not differ either between generations or between socioeconomic groups. They concluded that males are more readily influenced by environmental factors than are females.

Moorrees[34] in 1964 stated that because of the range in individual development observed at any age, chronologic age may be only a rough approximate of the actual level of maturation. In the same year, he collaborated with Reed and Chadha[35] in an examination of 232 cases, with eruption being graded from "emergence to reaching occlusal level," according to four stages of eruption. The authors felt that there was great conformity between males and females in patterns of change in dental arches when the data were grouped on a biologic rather than a chronologic scale, and that tooth eruption could be used to determine physiologic age.

In a historical note, Fanning[36] in 1964 reported that the number of teeth present in the mouth was first used as a maturational factor by Thompson in 1836 at the University of London. English law at that time stated that a child less than seven years old could not be held responsible for a capital crime. Thus, the presence or absence of the first permanent molar was used to ascertain whether the child's age was being given honestly by the parents. It was felt that teeth were the most suitable criterion for age assessment.

Dissatisfied with the value of the wrist plate as an indicator of maturation, Steel[37] noted that skeletal age from wrist plates may vary in children of the same chronologic age plus or minus two years, thus covering a four-year spread. As a result, he began judging dental maturation either by eruption or calcification, and since eruption is influenced by such environmental factors as early loss of teeth and crowding, he felt that study by calcification was the more reliable criterion.

In 1965 Steel et al[20] published a short, but excellent, review of the literature on the relationship between the developing dentition and general growth and development. They concluded that advanced eruptive development is associated with advanced general physiologic development. They also supported the 1955 article of Gleiser and Hunt[21] which asserted that calcification of tooth might be a more reliable measure of physiologic maturity than tooth eruption.

In 1965, after six years of research, Garn and Lewis[38] stated that there is a low correlation between maturational status and tooth formation but that this correlation increases as the subject nears puberty. This suggests a direct influence of steroidal hormones. They felt that 90 per cent of dental development is genetically determined and that only 10 per cent of the development should be attributed to nutritional status (i.e. caloric or protein adequacy). They also reported that early maturing children of both sexes are advanced in dental development, with teeth resembling bones in "degree of responsiveness" near puberty.

A thesis by Schwartz[39] in 1966 provides an excellent reference as to the validity of the human dentition as an indicator of physical maturity. He noted that Cramptom, Beak, Bean, Spear, Talmers and Pittorru had all found that those children with physiologic characteristics for a given chronologic age were also advanced dentally. He also stated that such authors as Sutow, Lamons and Gray, Lewis and Garn had suggested high correlations between skeletal age and the eruption of permanent teeth. On the other hand, he observed that Bambha, VanNatta, Gron, and Meridith felt that no definite relationship had been found between eruption of permanent teeth and skeletal maturation, even though they all agreed that skeletal maturation was certainly a sign of physiologic development. Schwartz concluded that the relationship or lack of one between skeletal age and dental development had not been adequately established previous to that time. He found that eruption and dental development (according to a 20-stage evaluation of tooth formation) was not as good an indicator of physiologic maturity as were height, chronologic age, and developmental age (on a Wetzel grid). He reported that the developmental status of dentition was not a good indicator of physiologic maturity for the 8-year, 7-month to 11-year, 0-month age group, but was a valid indicator for the 7-year, 0-month to 8-year, 6-month age group and also for the 11-year, 0-month to the 12-year, 6-month age group.

Garn et al[40] in 1967 implied that tooth formation and calcification are at best only moderately correlated with skeletal development and that genetic variations and the sequence of calcification invalidate overly-precise attempts at measuring dental age.

Also in 1967 Wolanski[41] published a paper entitled "New Methods - Evaluation of Tooth Formation." Wolanski's method of scoring was used in the development of this thesis and it is dealt with in detail in the Methods and Materials section.

Kraus, Clark, and Oka[42] are among several authors who have studied the relationship between mental retardation and abnormalities of the dentition. Their work in 1968 shows a significant association between mental retardation and retarded dental development and morphology.

Hiernaux[43] in 1967 stated that skeletal, dental and sexual development are the prime indicators of the maturation process. He reaffirmed, as many before him had done, that the correlation, though significant, is very low between permanent dentition and the skeletal and sexual maturation indices. His research was mainly concerned with possible influences of heredity, environment, and ethnic differences on these maturational states. He pointed to a 1964 article by Wurst, who stated that children of higher socioeconomic levels erupt teeth earlier than those in lower socioeconomic groups. This was reaffirmed by two Czechoslovakian authors, Valsik and Fabryova, who also in 1964 stated that earlier eruption of permanent teeth was definitely associated with general growth acceleration in the general population and that higher standards of living were involved. Hiernaux pointed out that the tempo of skeletal, dental and sexual maturation is greatly influenced not only by heredity but also by environment.

Sinclair[44] in 1969 indicated that dental age gives one a good idea of the child's progress toward maturity in the first half of the active growth period. In the second stage of growth, around puberty, dental age is not as good an indicator, but the development of the sexual apparatus seems to be more important. He stated that mental and psychological development is probably much more closely linked with radiographic and dental age than with chronologic age, pointing to many studies which suggest that those who mature physically ahead of schedule also score better on intellectual tests.

In 1970 three radiologists working independently and using Greulich and Pyle standards for evaluating skeletal development found it difficult to agree as to the validity of using bone age to judge maturation.[45] Interestingly, they found it especially difficult to agree in the case of short boys. Here there was a greater chronological age disparity than in tall girls, for example. Only 62 per cent of the time did the radiologists agree on bone age within six months. In all boys they found a delay of 29 months over chronologic age. At best, one gets from this article and others the feeling that there must be a better way to evaluate progress toward maturation in growth than by Greulich and Pyle standards for bone age.

In 1970 Legoux,[46] a French author, described a method of determining dental age by the size of pulp chambers and the stage of calcification and formation of the crown determined by radiographs in fossils of Neanderthal infants.

In 1970 an unpublished study by Rosen[47] evaluated the relationship of school readiness to permanent tooth eruption. A total of 87 kindergarten children, 49 boys and 38 girls, were examined for eruption of permanent teeth. Each child was given two Gesell School Readiness tests approximately five months apart. A dental examination was given at approximately the same time as each Gesell test and a third dental examination was given six months after the second examination. Rosen reported a relationship between the number of permanent tooth eruptions and the second Gesell test scores for males only. He suggested that the age when the evaluation of permanent tooth eruption is made may be critical. A relationship also appeared to exist between chronologic age and the Gesell test score, but again, only with respect to males. He felt that further research is indicated using boy and girl samples that are restricted to very small age ranges. Such tests may determine the existence of a "critical" age when the number of tooth eruptions may be used as an aid in determining a child's readiness for school.

Panoramic Radiography as a Means of Estimating Dental Development

Since Panoramic Radiography was chosen as a means of evaluating the calcification that is present in the unerupted and erupted permanent tooth mass, this review will deal with the advantages and shortcomings of that method. Among those authors describing the procedure are Kraske and Mazzarella[48] in 1961, Updegrave[49] in 1963, Thorpe[50] in 1967, and Guzman[51] in 1967. The procedures are standardized and are described in the Methods and Materials section.

In 1962 Kite, Swanson, Levin, and Bradbury[52] studied radiation and image distortion in the Panorex x-ray unit. They found that direct measurements of the total image size produced errors of 5 per cent or less in 67 per cent of the films, with the greatest distortion being in the molar areas. They also felt that three important criteria must be met in clinical studies to minimize image distortion: (1) the patient must be properly positioned according to standard techniques; (2) the patient must not move; and

(3) the operator must be aware of a possible difference in width and symmetry of the jaws being examined.

In 1963 Mitchell[53] did a panoramic study and found that the Panorex had specific value for showing the status of development and eruption of teeth at various ages.

Graber[54] in 1965 found that the Panorex gave an excellent picture of the growth and development stages of the mixed dentition. He concluded that since magnifications on the Panorex are relatively constant, space measurements can be made.

Bruggemann[55] in 1967 discussed vertical and linear distortion. Vertical distortion remained constant throughout the dental arch while linear distortion was found to be a negative distortion in the incisor area that moves to a positive distortion in the molar areas. He described Panorex technique and stated that with proper precautions distortion factors were minimal.

Christen and Segreto[56] in 1968 also studied the amount of distortion found in the Panorex. They reported vertical elongation as being 14 per cent in the premolar and molar area, where the teeth appear to be lengthened vertically and compressed horizontally. They also noted that with eccentric positioning there could be as much as 34 per cent horizontal compression. Whereas, Kite and Swanson used a calibrated wire in the buccal sulcus to evaluate corrective factors that compensated for image distortion, Christen and Segreto used metallic pins to determine these percentages.

Also in 1968, Yamani[57] supported the findings of Christen and Segreto on distortion by reporting that he also found the first molar area to reflect the greatest distortion on the Panorex.

In an interesting article on the histologic criteria for estimating the age of the developing human dentition, Calonius[58] in 1970 used the degree of development rather than eruption per se to determine the chronological age of fetuses and infants. He did serial sections of 92 cases to examine the developing dentition. These sections for age determination progressed from the occlusal of the developing tooth to the cervical. He found that the amount of enamel matrix formed was a useful guide in age estimation.

In 1970 Green and Aszkler[59] reported on a study of 69 sets of twins between the ages of 6.5 and 16 years. A Panorex was taken within one week of the birthday. Standard procedures were followed with the Panorex, i.e., 74 to 80 k.v.'s 10 m.a. 22 seconds, and the Panorex was then used to compare the dental development of several permanent mandibular teeth in these twins. One finding was that bilateral symmetry was found in mono and dizygotic twins. Green and Aszkler used a system described by Nola to evaluate the crown and root of the permanent canines, bicuspids, and first and second molars. The radiographs were rated twice independently and randomly and measurement error was determined by the difference between the first and second ratings. This difference was found to be 0.02 per cent, which was less than one stage of development in any case and the standard error of measurement was 0.23 stages. Green and Aszkler concluded that the Panorex is very dependable for rating dental development, that there is a strong genetic component of intra-alveolar dental development, and that this intra-alveolar dental development is bilaterally symmetrical in twins. This last conclusion confirms the study by Hotz in non-twins: he reported that 83 to 98 per cent of the time there was bilateral symmetry in developmental stages.

In another article concerning the dependability of the Panorex for rating dental development, Gilbert[60] reached two conclusions: (1) that distortion is minimized by proper positioning and by proper stabilization of the patient's jaw, and (2) that the Panorex shows the crown-root ratio clearly and in good detail.

In a thesis in 1966 Kuba[61] reported that the radiation hazard from Panorex is very low both for patient and operator. Since the operator was the main concern, Kuba stated that one could take 3,000 Panorex films per week without exceeding the established radiation protecting guides.

METHODS AND MATERIALS

The purpose of this study was to compare the relationships between chronologic age and dental developmental age and five areas of development. The hypothesis tested was that dental developmental age would be more useful than chronologic age in predicting various stages of development. The techniques for evaluating this hypothesis involved determining the dental developmental age of 74 children ranging in age from two to 11 years. A pilot study including 10 children served to review and standardize techniques used in the primary study. The primary study consisted of 74 children, 40 males and 34 females, who were chosen at random from patients visiting the Indiana University School of Dentistry Pedodontic Clinic. The socioeconomic status of each subject was determined by using the North-Hatt Occupational Scale.[62] According to this instrument, the subjects were categorized into the following socioeconomic statuses:

Upper upper class	-	0 children
Middle upper class	-	5 children
Lower upper class	-	5 children
Upper middle class	-	1 child
Middle middle class	-	18 children
Lower middle class	-	40 children
Upper lower class	-	1 child
Middle lower class	-	0 children
Lower lower class	-	0 children

The socioeconomic status of four subjects was not determined. Categorizing the 74 children by race, they divided into the following percentages:

Caucasian	-	71.6%
Negroid	-	23.0%
Oriental	-	5.4%

The method of panoramic radiography was chosen to evaluate dental developmental age. The S.S. White Panorex was used to record the developing dentition. The film was taken at 74 to 80 k.v., 10 m.a. and 22 seconds for each of the 74 children. In all cases the Panorex was taken within seven days of the interview for the developmental skills test. Attention was given to the exact positioning of the patient so that the occlusal plane was parallel to the floor and the midline positioned using the chin rest for proper alignment. In a number of children two panoramic radiographs were taken for each patient, the first with the standardized occlusal plane angle and the second with the occlusal plane at various angles to the floor. This method was used to ascertain whether exact head positioning was necessary for accurate interpretation of images produced.

All radiographs were examined and collectively evaluated at the conclusion of the data gathering. In this manner evaluation variability in terms of time was eliminated. The radiographs were scored independently without knowledge of the subject to whom they belonged. A random sample of panoramic radiographs were then scored independently in a double blind procedure by the author and a dental radiologist. The sample included radiographs that were taken with proper occlusal plane positioning and others that were not. In this manner, not only could ease of scoring be evaluated, but also the reliability and average difference in months could be calculated.

Dental Developmental Age

The scoring system used to determine dental developmental age from the radiograph was that developed by Wolanski[41] in 1966. He said either intraoral or extraoral radiographic techniques were acceptable for scoring interpretation. This scoring system was adapted from a method reported in 1963 by Moorrees, Fanning and Hunt,[63] who said, "This method distinguishes 13 developmental stages (14 in molars) in the development of 10 permanent teeth (upper and lower incisors, lower canines, premolars, and molars) and gives the average age of attainment as well as retardation and acceleration..." (Tables I, II, and III) The Wolanski method assigned scores to each stage of development, using (1) score or point tables, and (2) a dental age evaluation graph. Wolanski described the method as "the estimate of the development of a given tooth as the score corresponding with a given developmental stage for that tooth for the given sex." After the score estimates for all five or ten teeth, respectively, have been recorded, the sum of all the figures is obtained. This sum of scores becomes the basis for assigning dental age. Wolanski obtained that sum for 5 or 10 teeth from only one side of the jaw. The five-teeth sum was used for males up to their fifth year of life, and for females up to their fourth year; and the 10-teeth evaluation was used for males from their sixth year of life to their 20th, and for females from their fifth year of life to their 21st. Wolanski's technique for scoring did not allow computation of dental age for males in the fifth year of life, nor for females in the fourth year of life. Thus, no standard scoring method existed for the 4-year-old females and for the 5-year-old males in the study. It was concluded that those subjects falling in these age ranges should be eliminated in order that the correlations could be made without introducing into the analysis additional variables (i.e. a second scoring method). This resulted in deleting 21 of the 74 subjects. Wolanski stated that although he evaluated only one side of the jaw, if a radiographic method was available for analysis of the other side, then the score estimate could equal the average of the sums for the two sides. The literature suggests that dental structures develop fairly equally on both sides of the jaw.

Developmental Skills Age Inventory

After a procedure had been established to determine the child's dental age by evaluating the development and calcification stages of the tooth, it was necessary to ascertain the developmental age or ages of the child. The instrument selected was the Developmental Skills Age Inventory by Alpern and Boll.[4] The parent (in all cases the mother) was interviewed by one examiner only. The interview was conducted in a room void of distractions and only those items listed in the Alpern-Boll Developmental Skills Inventory were used to collect data. Before conducting the inventory, the interviewer received instructions from Dr. Alpern. After 10 interviews had been conducted, the results of procedures were reviewed and analyzed and corrections and suggestions in the administration of the instrument were made and noted.

The following is a description of that instrument:

> The Developmental Skill-Age Inventory is an instrument which has been designed to allow any medical, educational, or psychological professional, after brief training, to evaluate accurately the major developmental skills of children with functioning abilities from birth to 12 years of age. Ideally, a comprehensive and precise evaluation of a child's development involves an expensive and time-consuming examination by a variety of experts with competency in the areas of physical, language, personal/social, and educational development. The present inventory permits a reliable screening of all of these developmental areas in a short time by evaluators who need not be trained as developmental experts.

The inventory provides an individual profile which depicts a child's developmental age level by offering his particular skills in age norms in the five areas briefly described below:

Physical Age - This scale assesses the child's physical developmental age by determining the mastery of abilities requiring combinations of large and small muscle coordination, strength, stamina, flexibility, and sequential control skills.

Self-Help Age - This scale assesses children's abilities to cope independently with the environment by evaluating functioning in such socialization tasks as eating, dressing, and working, and to evaluate generally the degree to which they are capable of responsibly caring for themselves and others.

Social Age - This scale assesses the child's interpersonal relationship abilities. The child's emotional needs for people and the modes of relating to peers, siblings, and various adults exemplify the skills evaluated in measuring the child's functioning in the social structure of the culture.

Academic Age - This assesses the child's intellectual abilities by evaluating, at the pre-school levels, the development of skills prerequisite to scholastic functioning and at the school age levels, actual academic achievements.

Communication Age - This scale assesses the child's expressive and receptive language skills, both through the verbal and non-verbal modalities.

The technique of the instrument involves determining whether the child does or does not display certain skills. Determination of the child's actual accomplishments allows comparison to normative data - i.e. the specific age children usually have mastered each skill. Anyone who is sufficiently well acquainted with the child can provide the necessary information (though for standardization we interviewed the mother only). Thus, the instrument is actually an interview which can be self-administered, e.g. a teacher evaluating her pupils, or used as a structured-interview technique, e.g. a public nurse interviewing a child's mother. The instrument requires approximately twenty minutes to administer and score.[4]

RESULTS

Table IV indicates the reliability of two independent raters. In no case was the difference in estimated dental developmental age greater than five months, the average difference being 0.7 of one month (with an age range possibility of two to 11 years).

Table V indicates a highly significant correlation between chronologic age and dental age (.95++) in children ages two to 11 years. The correlations between those two indices and the five developmental skills ages were also highly significant.

Table VI indicates the same correlations with the age group divided into the categories of preschool (2-5 years), elementary (5-8 years), and intermediate (8-11 years). Those correlations are highest in the youngest group and tend to decrease through the elementary and intermediate age ranges. The correlations between chronologic and dental ages also decreases in the same manner from .96++ in the youngest group to .38 in the oldest.

Table VII indicates the correlations obtained when the three age groupings were subdivided into originally rateable, originally non-rateable, and combined cases. The correlations remained high and significant in the 2-5 group using the original and the combined cases. This is also true for the same groups in the 5-8 range. In both the 2-5 and the 5-8 ranges the correlations of the deleted cases were low and in general not significant.

Table VIII indicates the correlations found in the three age groupings further subdivided by sex. The same trend persists of high correlations in the youngest group, decreasing as the child becomes older. In children from 2-8, correlations were significant for both sexes but were consistently higher for males than females.

TABLES AND FIGURES

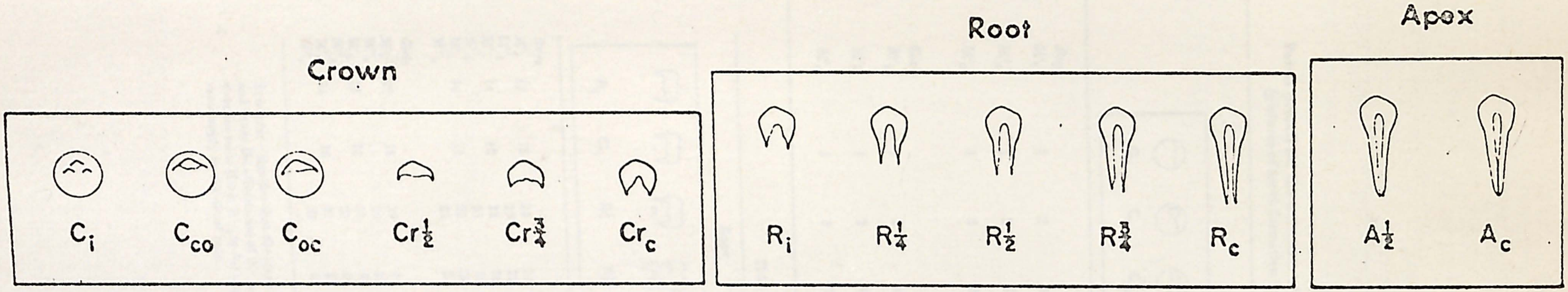
Table I

Stages (and their coded symbols) of tooth formation
(from *Moorrees, Fanning and Hunt*, 1963)

Coded symbol	Stage
C_i	Initial cusp formation
C_{co}	Coalescence of cusps
C_{oc}	Cusp outline complete
$Cr^1/_2$	Crown $^1/_2$ complete
$Cr^3/_4$	Crown $^3/_4$ complete
Cr_c	Crown complete
R_i	Initial root formation
Cl_i	Initial cleft formation
$R^1/_4$	Rooth length $^1/_4$
$R^1/_2$	Rooth length $^1/_2$
$R^3/_4$	Rooth length $^3/_4$
R_c	Rooth length complete
$A^1/_2$	Apex ½ closed
A_c	Apex closure complete

Table II

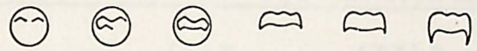
Points (scores) for the estimation of dental age of Incisors (I), Canine (C) and Premolars (P) in boys and girls (pictures of tooth formation from *Moorrees, Fanning and Hunt*, 1963). Symbols see Table III



	C_i	C_{co}	C_{oc}	$Cr_{1/2}$	$Cr^2/_3$	$Cr_{3/4}$	Cr_c	R_i	$R_{1/4}$	$R^1/_3$	$R_{1/2}$	$R^2/_3$	$R_{3/4}$	R_c	$A_{1/2}$	A_c
Boys																
I_1 max.	*	*	*	*	–	*	13	–	17	–	19	21	23	25	×	×
I_2 max.	*	*	*	*	–	*	13	–	17	–	19	21	23	27	×	×
I_1 mand.	*	*	*	*	–	*	*	–	*	–	26	28	30	32	35	37
I_2 mand.	*	*	*	*	–	*	*	–	21	22	24	26	28	30	32	35
C	1	2	4	8	–	11	15	18	22	–	31	–	38	40	46	51
P_1	1	3	5	8	–	11	14	17	21	–	27	–	32	34	40	46
P_2	1	3	6	8	–	10	14	16	19	–	26	–	31	34	38	44
Girls																
I_1 max.	*	*	*	*	–	*	12	–	16	–	18	20	22	24	27	×
I_2 max.	*	*	*	*	8	–	12	–	15	–	17	19	21	24	26	×
I_1 mand.	*	*	*	*	–	*	*	–	20	–	22	24	26	28	31	32
I_2 mand.	*	*	*	*	–	*	*	–	20	22	25	27	28	31	33	35
C	1	2	4	7	–	11	15	18	20	–	27	–	32	34	38	43
P_1	1	3	5	8	–	11	14	17	20	–	27	–	31	33	38	42
P_2	1	3	6	8	–	10	13	16	18	–	23	–	28	31	36	43

Table III

Points (scores) for the estimation of dental age of Molars (M) in boys and girls (pictures of tooth formation from *Moorrees, Fanning and Hunt*, 1963)



	Crown					
	C_i	C_{co}	C_{oc}	$Cr\frac{1}{2}$	$Cr\frac{3}{4}$	Cr_c
Boys						
M'_1	1	2	3	5	7	10
M'_2	1	2	5	7	9	12
M'_3	1	3	5	7	10	12
Girls						
M'_1	1	2	4	5	7	10
M'_2	1	2	4	6	8	12
M'_3	1	3	5	8	9	11

Table III (continued)

	Root						Apex	
	R_i	Cl_i	$R\frac{1}{4}$	$R\frac{1}{2}$	$R\frac{3}{4}$	R_c	$A\frac{1}{2}$	A_c
Boys								
M'_1	12	15	20	21	23	24	29	35
M''_1			19	21	24	26	30	37
M'_2	14	18	23	26	29	31	34	42
M''_2			23	26	30	32	36	44
M'_3	14	18	22	24	27	28	33	39
M''_3			21	24	27	29	35	42
Girls								
M'_1	12	15	19	21	23	24	27	33
M''_1			19	21	23	25	29	36
M'_2	15	18	23	26	29	31	35	43
M''_2			23	26	30	31	36	44
M'_3	14	16	21	25	27	29	33	41
M''_3			21	25	28	30	34	44

Symbols: – signifies that the stage was not included; * or × signifies a lack of data and hence the elimination of the particular stage from this system; M'signifies that data for roots (from $R^1/_4$ to A_c) apply to the mesial root; M″ signifies that data for roots apply to the distal root.

Table IV

Reliability: Ten Randomly Selected Panorexes
Assigned Dental Ages by Two Independent Raters

Randomly Selected Subjects by Number	Dental Age in Months (I)*	Dental Age in Months (II)*	Difference in Months
20	58 mo.	60 mo.	+2
22	92 mo.	91 mo.	-1
24	53 mo.	52 mo.	-1
27	58 mo.	60 mo.	+2
28	62 mo.	63 mo.	+1
46	70 mo.	70 mo.	0
48	112 mo.	112 mo.	0
49	82 mo.	80 mo.	-2
61	82 mo.	77 mo.	-5
62	98 mo.	95 mo.	-3
			0.7 Month Average Difference

*(I) Author

*(II) Dental Radiologist

Table V

Correlations Between Chronologic Age and
Dental Age With Five Developmental Skills Ages

Age Range		Physical Skill Age	Self-Help Skill Age	Social Skill Age	Academic Skill Age	Commun. Skill Age	CA & DA
2-11 yrs.	CA	.90++	.92++	.90++	.93++	.91++	
							.95++
N = 53	DA	.86++	.89++	.84++	.88++	.87++	

CA = Chronologic Age

DA = Dental Age

++ = 1% (.01) significance level

N = Number of subjects

Table VI

Correlations Between Chronologic Age and Dental Age With Five Developmental Skills Ages in Three Age Groupings

Age Group		Physical Skill Age	Self-Help Skill Age	Social Skill Age	Academic Skill Age	Commun. Skill Age	CA & DA
I. 2-5 yrs.	CA	.91++	.77++	.76++	.71++	.77++	.96++
N = 12	DA	.89++	.76++	.68++	.75++	.88++	
II. 5-8 yrs.	CA	.74++	.65++	.68++	.77++	.66++	.77++
N = 24	DA	.48+	.53++	.48+	.54++	.52++	
III. 8-11 yrs.	CA	.14	.62++	.54+	.65++	.39	.38
N = 17	DA	.10	.51+	.02	.00	-.05	

CA = Chronologic Age

DA = Dental Age

+ = 5% (.05) significance level

++ = 1% (.01) significance level

N = Number of subjects

Table VII

Correlations Between Chronologic Age and Dental Developmental Age with Five Developmental Skills Ages for Three Age Groupings Subdivided into: a) those originally rateable children, b) those originally non-rateable children in the 4-5 year old range, c) and all children combined

	Age Group		Physical Skill Age	Self-Help Skill Age	Social Skill Age	Academic Skill Age	Commun. Skill Age	CA & DA
I.	2-5 yrs. OR N = 12	CA	.77++	.75++	.80++	.69+	.73++	.95++
		DA	.83++	.73++	.78++	.78++	.74++	
	ONR N = 10	CA	.43	.36	-.07	.16	-.04	.56
		DA	.10	-.02	-.05	-.41	-.33	
	Combined N = 22	CA	.73++	.73++	.73++	.65++	.66++	.92++
		DA	.71++	.69++	.67++	.67++	.62++	
II.	5-8 yrs. OR N = 23	CA	.73++	.64++	.67++	.77++	.65++	.78++
		DA	.44+	.51+	.44+	.52+	.49+	
	ONR N = 12	CA	.53	.56	.64+	.83++	.59+	.48
		DA	.18	.21	.47	.37	.17	
	Combined N = 35	CA	.73++	.71++	.72++	.83++	.71	.80++
		DA	.50++	.57++	.55++	.61++	.52++	
III.	8-11 yrs. OR N = 17	CA	.14	.62++	.54+	.65++	.39	.38
		DA	.10	.51+	.02	.00	-.05	

N = Number of Subjects
CA = Chronologic Age
DA = Dental Age
\+ = 5% (.05) significance level
++ = 1% (.01) significance level
OR = Originally rateable
ONR = Originally non-rateable

Table VIII

Correlations Between Chronologic Age and Dental Age with Five Developmental Skills Ages in Three Age Groupings Subdivided by Sex

	Age Group		Physical Skill Age	Self-Help Skill Age	Social Skill Age	Academic Skill Age	Commun. Skill Age	CA & DA
I.	2-5 yrs. Males N = 11	CA	.70+	.94++	.83++	.70+	.75++	.93++
		DA	.67+	.89++	.76++	.79++	.73++	
	Females N = 11	CA	.73++	.54	.71+	.60+	.60+	.91++
		DA	.76++	.44	.59	.47	.51	
II.	5-8 yrs. Males N = 18	CA	.62++	.77++	.76++	.87++	.72++	.84++
		DA	.80++	.66++	.62++	.71++	.54++	
	Females N = 17	CA	.68++	.59+	.69++	.79++	.69++	.75++
		DA	.39	.46	.48+	.49+	.50+	
III.	8-11 yrs. Males N = 12	CA	.19	.54	.48	.57+	.17	.34
		DA	.02	.17	.11	.01	-.24	
	Females N = 5	CA	.16	.83	.90+	.82	.79	.53
		DA	.83	.55	.22	.04	.10	

CA = Chronologic Age

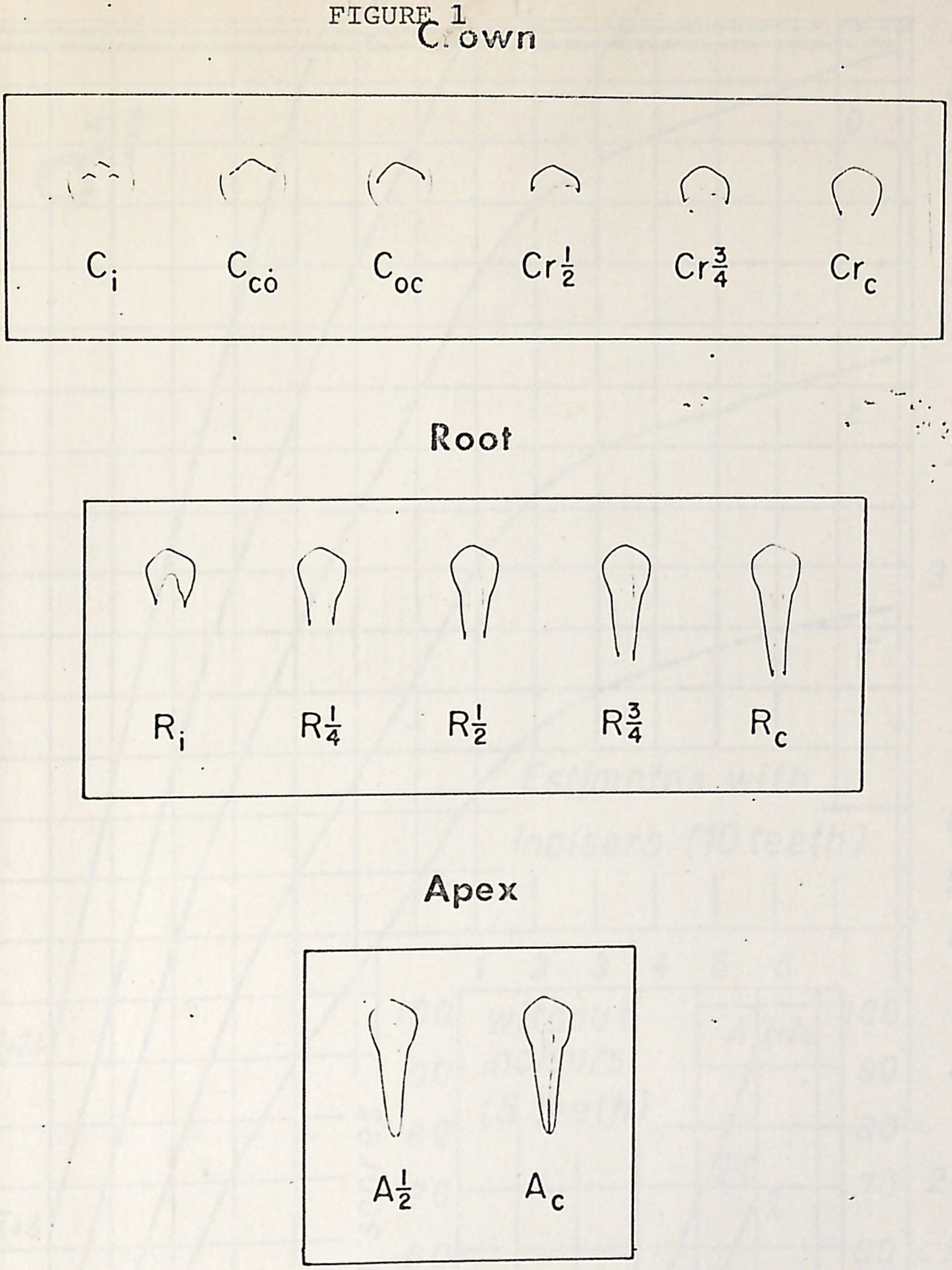
DA = Dental Age

+ = 5% (.05) significance level

++ = 1% (.01) significance level

N = Number of subjects

FIGURE 1



Stages of tooth formation for assessing the development of single-rooted teeth

TOOTH-FORMATION STAGES AND
THEIR CODED SYMBOLS

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

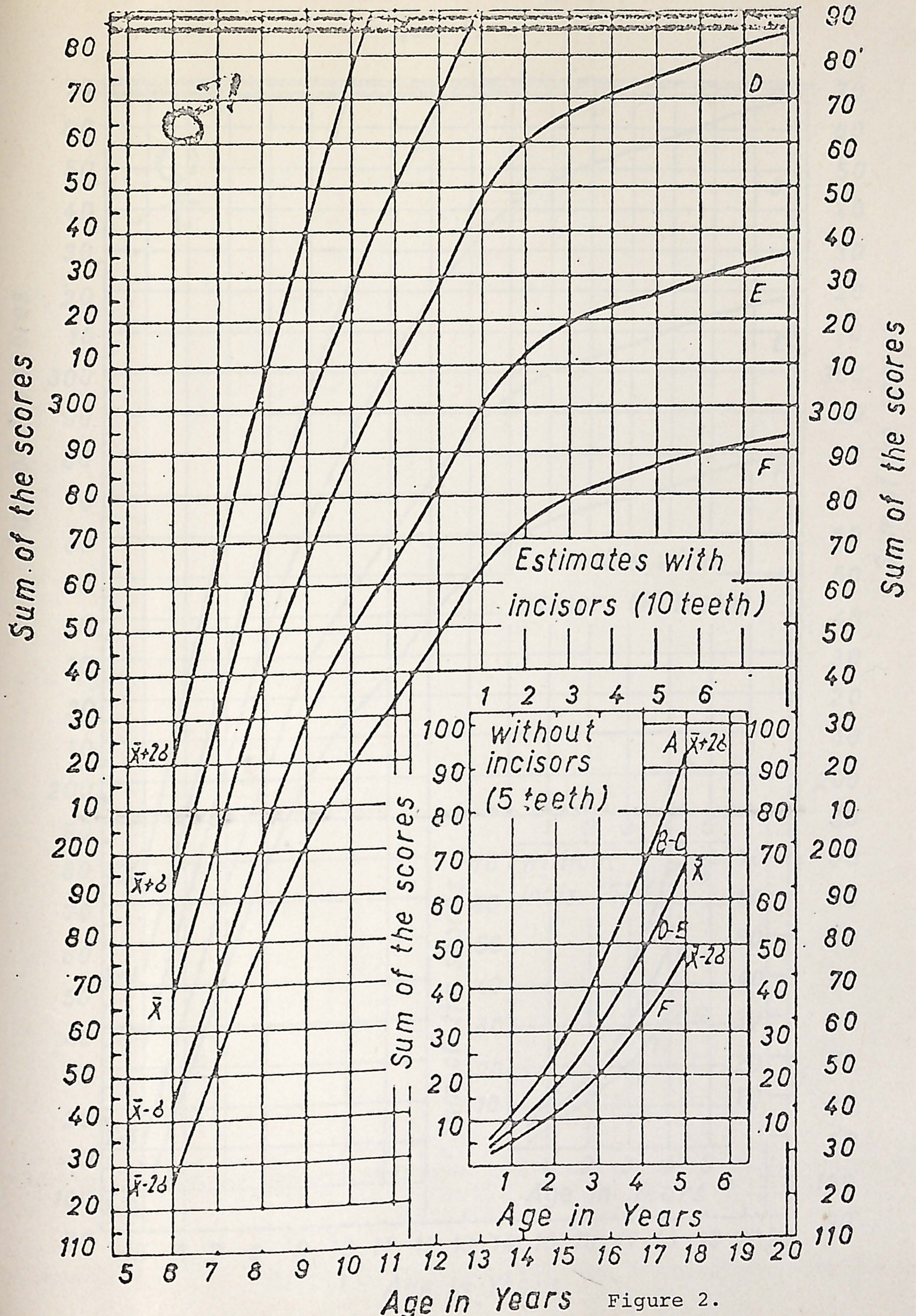

Sum of the scores
Age in Years
Estimates with incisors (10 teeth)
without incisors (5 teeth)
D
E
F
$\bar{X}+2\delta$
$\bar{X}+\delta$
$\bar{X}$
$\bar{X}-\delta$
$\bar{X}-2\delta$
A
B-C
D-E

Figure 2.

Figure 3.

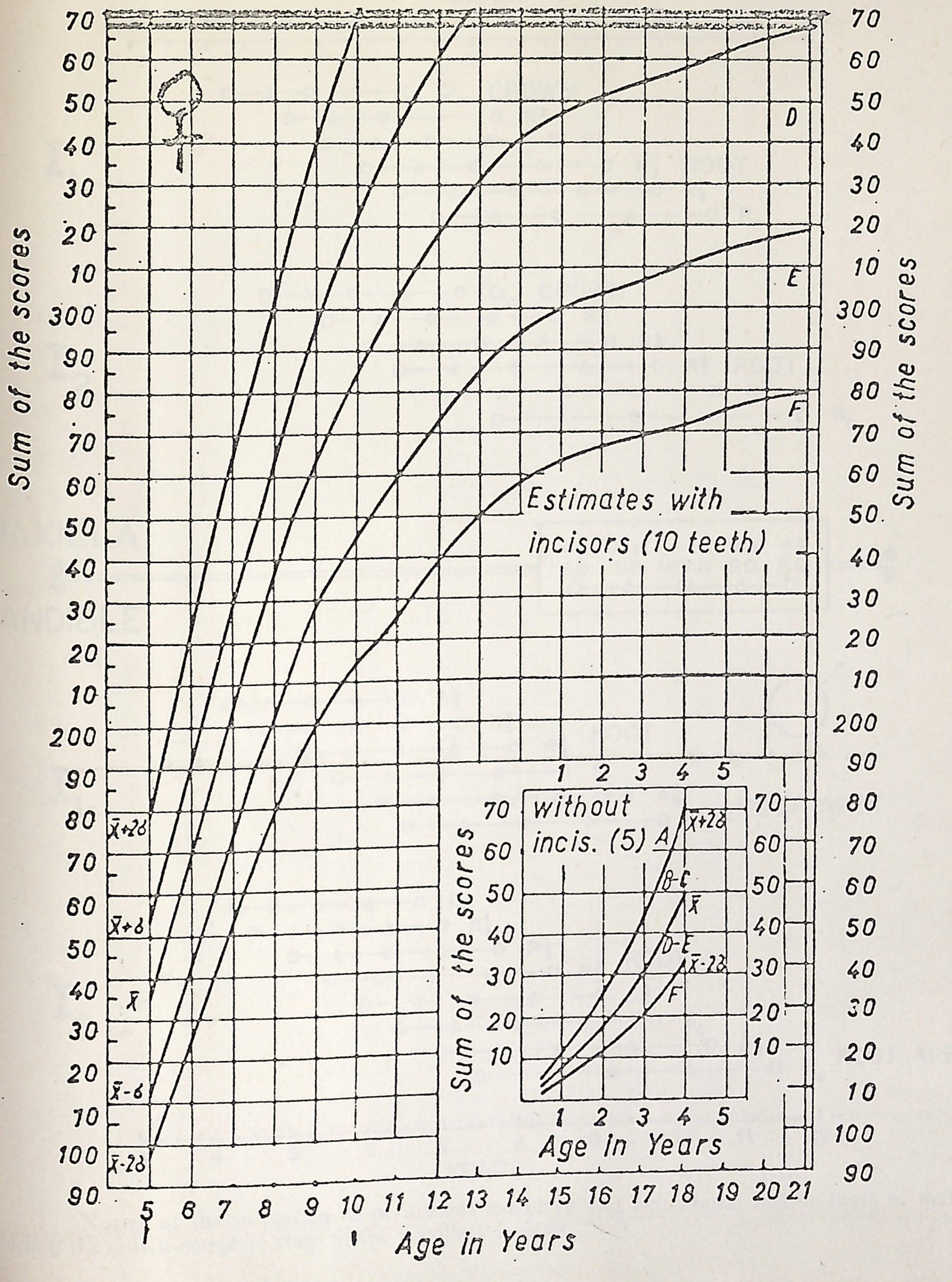
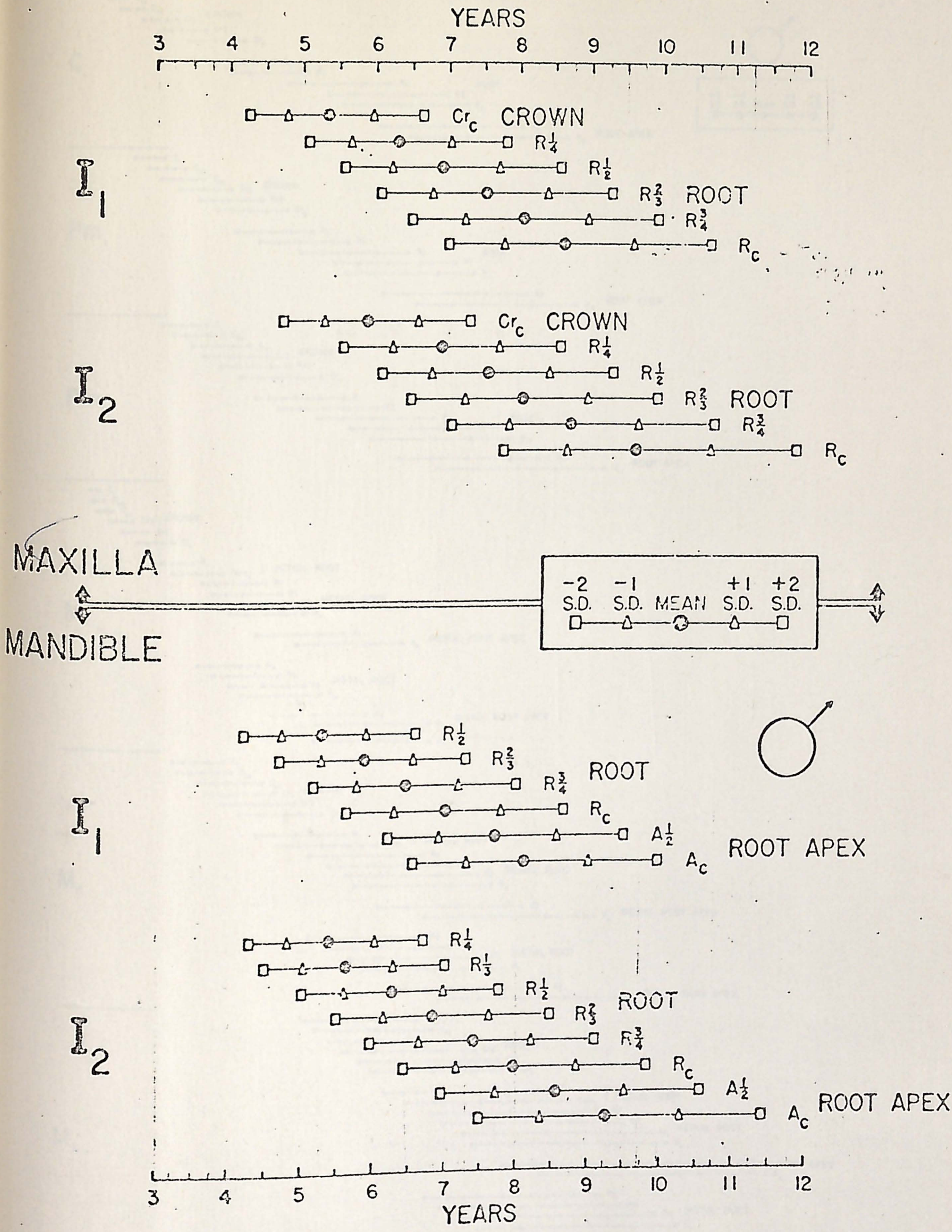

Sum of the scores
Sum of the scores
D
E
F
Estimates with incisors (10 teeth)
without incis. (5)
A
B-C
D-E
F
X̄+2δ
X̄+δ
X̄
X̄-δ
X̄-2δ
Age in Years
Age in Years

Figure 4.



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

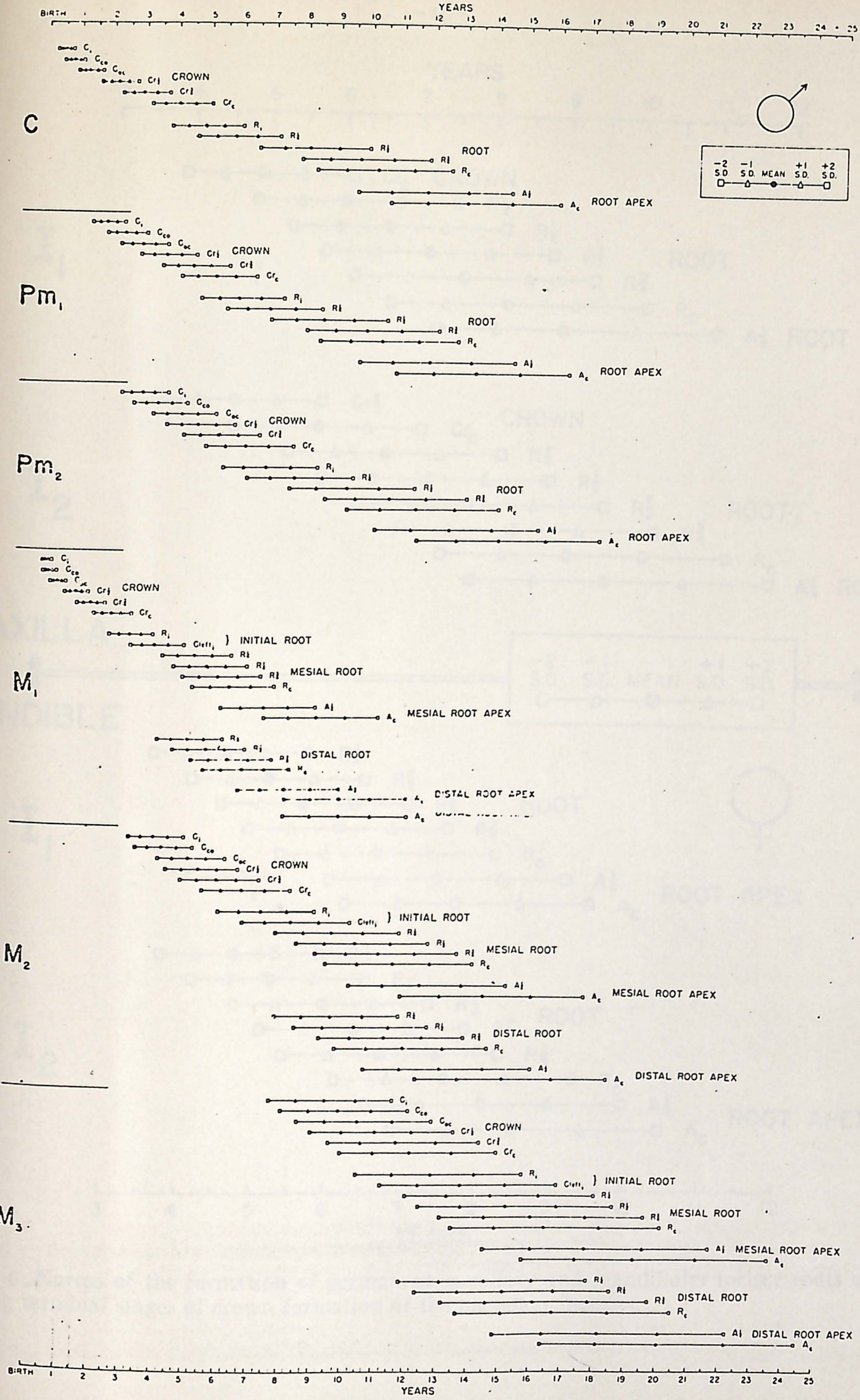


Fig. 5.—Norms of tooth formation of permanent mandibular canines, premolars, and molars of males

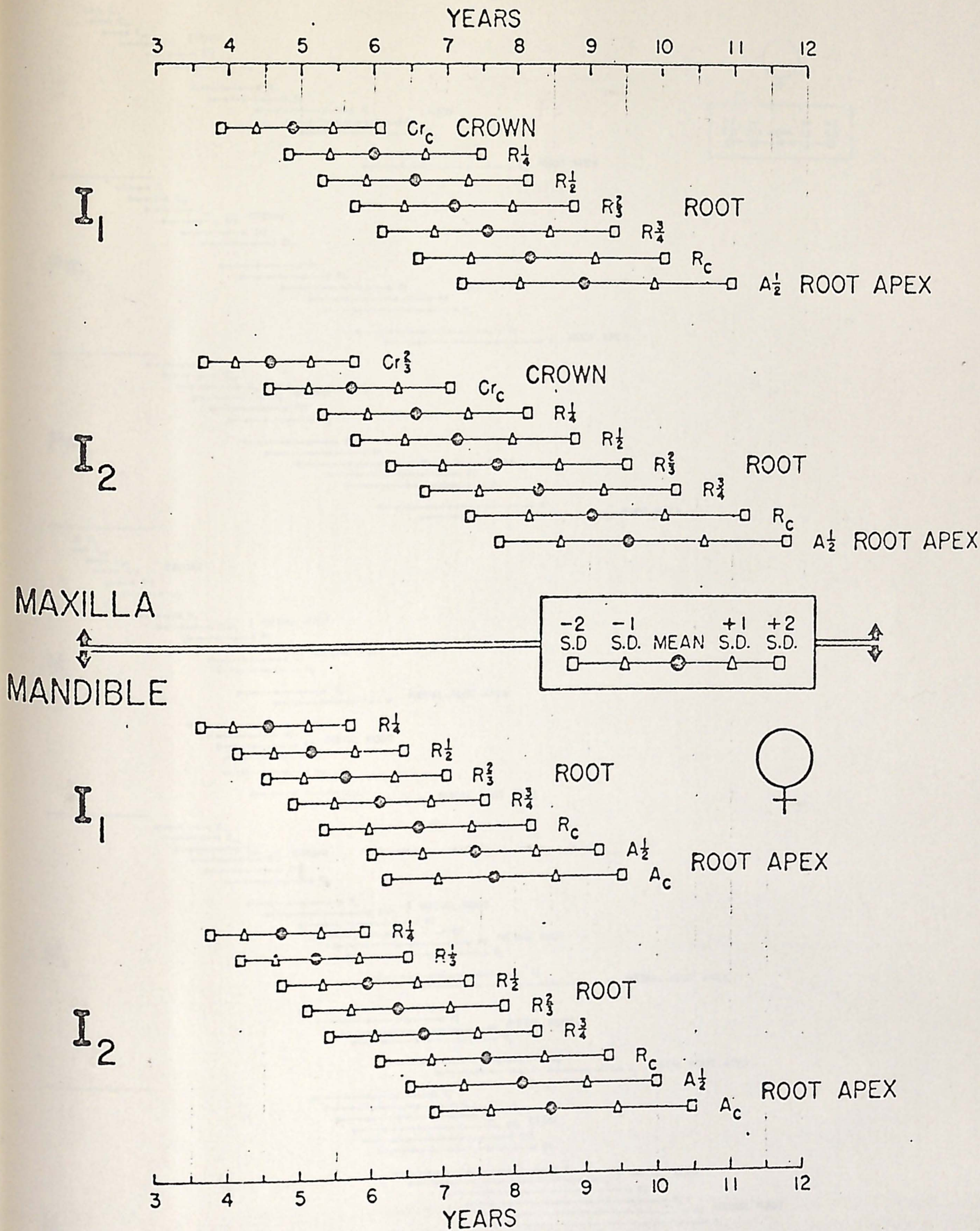


Figure 6. Norms of the formation of permanent maxillary and mandibular incisor roots of females including terminal stages of crown formation of the maxillary incisors.

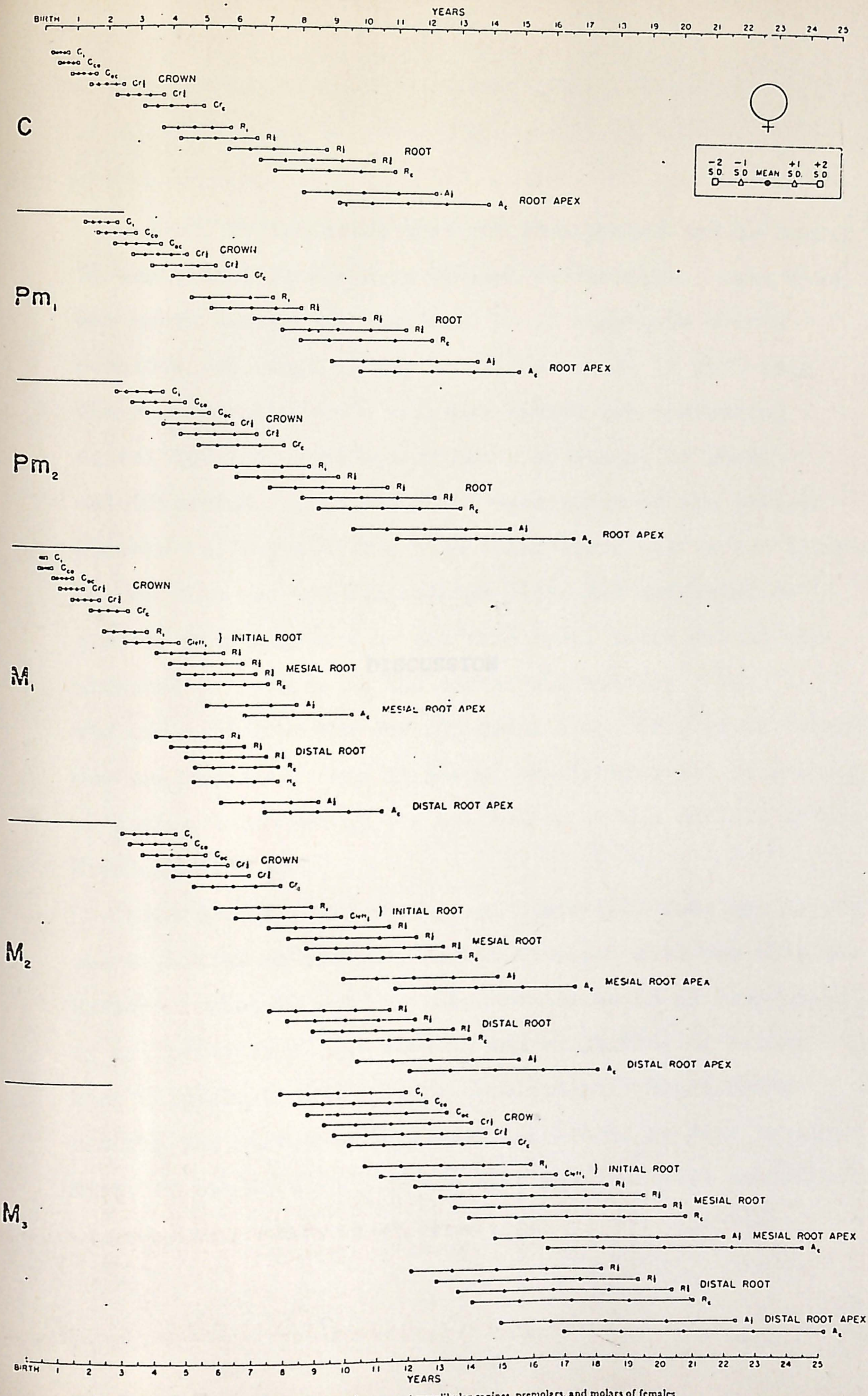


Figure 7. Norms of tooth formation of permanent mandibular canines, premolars, and molars of females

DISCUSSION

Table IV indicates that the radiographs can be scored by individual raters with minimal differences. Less than one month difference was found on 10 Panorexes with a possible age range of two to 11 years. It is felt that the Panorex provides a reliable method for evaluating dental developmental age by means of stages of tooth calcification. When two films were taken of one patient wherein the angle of the mandibular floor was varied slightly in one film and the midsaggital plane did not coincide exactly with the mark on the chin rest, there was no significant difference in the dental age scoring. That is, the estimation of the developmental stage of a given tooth was unaltered and thus different positioning was determined as having no effect in the estimation of the child's dental developmental age.

The author feels that image distortion does not affect one's ability to evaluate dental developmental age from the Panorex. Whether the root appears elongated or compressed is not critical to the scoring and evaluation of either cusp calcification or apical development. By studying closely the different developmental stages in root development, it can be seen that the apex has a classic anatomical appearance for each stage of development, the interpretation of which is not affected by either vertical or horizontal distortion.

It appears from the present data that the Panorex does overcome objections regarding image distortion, score reliability, and head positioning, and can be used to evaluate the overall dental development of a child, and to accurately estimate the child's dental age in months.

Table V indicates the correlation between chronologic age and dental developmental age and then between those two indicators and physical age, self-help age, social age, academic age, and communication age. It can be seen from Table V that for the 53 subjects between the ages of two to 11 (i.e. at the 1 per cent significance level) all 11 correlations were high and significant. The correlation between dental developmental age and chronologic age was sufficiently high so that no discriminations could be made as to their relative effectiveness in regards to developmental ages.

It is felt that such high correlations were found because both dental developmental age and the five developmental age scales were all constructed according to their relationship to chronologic age and therefore the high correlation reported in Table V primarily reflected a built-in relationship between all the scales and chronologic age. A second analysis was then performed which was designed to delete the non-discriminating effect produced by the wide age range of subjects in the original analysis.

For the second analysis the total sample of subjects ranging in age from two to 11 years, was broken down into three age grouped subsamples: Group I, ages 2-5; Group II, ages 5-8; and Group III, ages 8-11. Table VI shows the results of the analysis by age groups. Two interesting factors are demonstrated with the correlations depicting the relationships using narrower age groupings. First, the relationship between chronologic age and dental developmental age decreases steadily with increasing age. Table VI reveals that chronologic age and dental developmental age have a correlation of .96 in the 2-5 year age range, which drops to .77 in the 5-8 year age range, and to .38 in the 8-11 year age group. Second, the correlations between the five developmental ages and both chronologic age and dental developmental age tend to decrease as the child gets older. It can be reasoned that all developmental tasks have wider ranges as the child gets older. For example, if we were to predict when a child sits unaided, the normative age range for this task would be very narrow, i.e. a few weeks. With a later developmental task, however, the normative range is much wider. For instance, the age at which a child learns to ride a two-wheel bicycle might be four years of age, while other children might not learn until the age of seven or eight and still be "normal." Thus, the achievement of all developmental tasks becomes less specific as chronologic age increases. The lower correlations found between dental developmental age and chronologic age with the five developmental areas as the age increases, then, are probably a function of the wider normal range for all developmental tasks with increasing age.

Table VI offers the additional interesting data that during ages 2-5, both chronologic age and dental developmental age do equally well in predicting the developmental skills age of the child, but that during ages 5-8, chronologic age does a significantly better job at predicting those skills (i.e. though both chronologic age and dental developmental age are significant at the 1 per cent level tending to indicate that chronologic age does show a higher degree of reliability). The table also shows that at ages 8-11, only chronologic age is significant in correlation to the five developmental skills ages.

As the former analysis strongly suggested a differential age factor, it was considered worthwhile to include the data from the 21 subjects not scorable by the Wolanski[41] method, in order to see the effect of a second scoring system on the statistical analysis.

Attempts to determine the original reason for the missing ages in the Wolanski study were unsuccessful. It was then decided to return to Moorrees, Fanning, and Hunt's[62] 1963 article ("Age Variation of Formation Stages for Ten Permanent Teeth") as this study provided the data that were adapted by Wolanski in his determination of dental developmental age. In this article, the authors state:

> 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.

Using the graphs and standards set out in this article, the 21 cases of 4-year-old females and 5-year-old males were now individually assessed by rating individual teeth and plotting them on the graphs that Moorrees supplied. The dental developmental age of each tooth was determined in months and then those figures were summed and divided by the number of teeth used to establish the dental age for the individual. The dental ages determined from that procedure were then added to the original 53 cases, plotted on Wolanski's graph and the relationships between chronologic age and dental developmental age with the five developmental scales for all 74 subjects were determined.

Table VII shows the results of that statistical analysis with the increased sample size. Table VII indicates that the additional 21 cases, done on the basis of Moorrees' chart, seem to lower the correlations in the two to five year age group. The correlation between chronologic age and dental developmental age fell to .56 and there were no significant correlations between either of those indices and the developmental ages. The correlations in the five to eight age group using the chart supplied by Moorrees shows a low correlation between chronologic age and dental developmental age, as it did in the two to five group; and in this case only a few of the correlations are significant. In evaluating these findings it was hypothesized that the critical point in the lowering of the correlations is the fact that in the two to five group those supplemental cases added were all females. This, of course, was the case as the Wolanski method deleted males ages 5-6 and females ages 4-5. The next logical step was to perform an analysis of the data by sex, inasmuch as the differences between the correlations in Table VI and VII suggest a relevant sex variable. For the next analysis, the subjects were broken down into age and sex groupings.

Table VIII shows the statistical analysis done on males age two to five and females age two to five, on males age five to eight and females age five to eight, and on males age eight to 11 and on females age eight to 11, using the combined data of both techniques (Wolanski's and Moorrees').

As evident from the earlier tables, Table VIII also reveals a trend in which the younger the child, the higher and more significant the correlations. In the two to five group, correlation between chronologic age and dental developmental age remains high and there is little doubt that the correlations are stronger for males than for females, except in the physical skills age category. It is important to note here that the correlation for both male and female between chronologic age and dental developmental age remains extremely high and significant. A very interesting finding revealed by Table VIII is that in the five to eight group the males' correlations with dental developmental age are much higher than for females. In other words, dental developmental age is a better predictor relative to the development of the five to eight-year-old male than to the development of the five to eight-year-old female. However, in no case is dental developmental age a better predictor than chronologic age for either sex, except for physical skills age. Again looking at the relationship of dental developmental age to chronologic age, one can note that both in the male and the female groups the correlations are significant to the 1 per cent level. In the eight to 11 groups there was only one significant correlation each for the male and female subgroupings. Furthermore, dental developmental age and chronologic age were not significantly related for either male or female groups. As the number of subjects in both males and females were so small in these oldest subgroups, any conclusions derived from this part of the table must be extremely tentative.

SUMMARY AND CONCLUSIONS

The purpose of this study was to compare the relationships of chronological age and dental developmental age in five areas of development. The hypothesis tested was that dental developmental age would be more useful than chronological age in predicting various stages of development. The technique for evaluating this hypothesis involved determining the dental developmental age of 74 children ranging in age from two to 11 years. A pilot study including 10 children was conducted to review and standardize techniques used in the main study. The 74 children in the main study consisted of 40 males and 34 females, chosen at random from patients at the Indiana University School of Dentistry Pedodontic Clinic. The socioeconomic status of each subject was determined by using the North-Hatt Occupational Scale.

The dental developmental age was determined with the aid of panoramic radiography. All radiographs were examined and collectively evaluated at the conclusion of the gathering of data. The radiographs were scored independently, with the observer being unaware of the identity of any child. A random sample of panoramic radiographs were then scored independently in a double blind procedure by the author and a dental radiologist. The scoring system for determining dental developmental age from the radiographs was developed by Wolanski in 1966.

After a procedure had been established to determine the child's dental age by evaluating the development and calcification stages of a tooth, it was necessary to ascertain the developmental age or ages of the child. The instrument selected was the Developmental Skills Age Inventory by Alpern and Boll.

The results of the study show that dental developmental age is an excellent predictor of children's developmental skills. However, it seems no more accurate than chronologic age in predicting developmental skills when the subjects used span a wide age range (i.e. two to 11 years).

While the data from this study show that dental developmental age does correlate well with developmental skills, especially in the younger age ranges, the correlation between chronologic age and developmental skills is consistently higher (except in a few isolated cases), but not significantly so. It appears that dental developmental age is a more valid indicator of the general developmental skills of the child for the male than for the female. This holds true for children from two to eight years of age. The correlations between chronologic age and dental developmental age are highly significant in this young age group and consistently decrease as the child becomes older.

With these thoughts in mind, a number of suggestions are in order:

(1) The study indicates that the complexity of interactions between the age and sex of the child justifies refinements in data analysis. This could be accomplished by increasing the number of subjects and decreasing the age ranges. Tables V through VIII show that a breakdown by age and sex significantly affects the correlations obtained. Any study that purports to show high or low correlations between chronologic age and dental developmental age and other growth indices must be carefully examined for size of age range and sex differentiation of subjects. The present study attests to the importance of that consideration since correlations changed significantly when the original two to 11 year age range was divided into classic age groups, i.e. preschool (2-5 years), primary (5-8 years), and intermediate (8-11 years). The correlations were significantly affected again when those age groups were further subdivided by sex, i.e. males 2-5, females 2-5, males 5-8, females 5-8, males 8-11, and females 8-11. Thus, more refined information would definitely be possible as a result of limiting the study to six-year-old females, for example.

(2) A more comprehensive study of how to determine the dental developmental age of the four-year-old female and

the five-year-old male is needed. However, the methodology for determining dental developmental age in these groups is inadequate, since it does not permit assessment of one year of life in each sex. We need to know why such a condition exists. Perhaps this period in dental maturation coincides with other aspects of physiologic maturation which are also inconsistent and unpredictable. For instance, during the pubescent growth spurt (boys at approximately 14 years of age and girls at 13 years), height is not an accurate criterion of the past or future status of the child's overall growth. The tall child at age seven is likely to be the tall child at age 17, but during that 13 to 14 year age span growth prediction seems very inconsistent. Perhaps this same phenomenon occurs in dental maturation at the four to five year age span. A study of dental maturation of the four and five-year-old period is indicated.

(3) More study is needed concerning the reliability of the Panorex as a survey of dental developmental age, regardless of the distortion factor which is inherent in this radiographic technique.

(4) This study has dealt with apparently normal children, in determining correlations between chronologic age, dental developmental age, and the functioning level of children in five developmental skills. The results do not assume any

correlations with those children not in that category, i.e., the cerebral palsied, or the mentally retarded. We know that chronologic age has nothing whatever to do with developmental skills, functioning, or mental age in these children. Perhaps dental developmental age is a better indicator for them.

More study of child development and maturation is imperative for those of us who treat children daily, if we are to mature in our understanding of the child patient.

REFERENCES

1. McDonald, R. E.: Dentistry for the Child and Adolescent. St. Louis, C. V. Mosby Co., 1969.

2. Ilg, Frances L., Ames, Louise B.: The Gesell Institute's Child Behavior. New York, Harper & Row, 1955.

3. Lampshire, E. L.: Control of Pain and Discomfort, Chapter 31, Current Therapy in Dentistry, Vol. 4, St. Louis, C. V. Mosby Co., 1970.

4. Alpern, G. D., Boll, T. J.: Developmental Skill-Age Inventory.

5. Ilg, Frances L., Ames, Louise B.: School Readiness. New York, Harper & Row, 1964-1965.

6. Massler, Maury and Schour, I.: Studies in tooth development: Theories of eruption. Am. J. Orth. & Oral Surg. 27:552, 1941.

7. Jones, Mary and Bayley, Nancy: Physical maturing among boys as related to behavior. J. Ed. Psyc. 41:129, 1950.

8. Beik, A. K.: The physiological age and school entrance. Pedogogical. Seminary and J. Genetic Psyc. 20:277, 1913.

9. Perkins, F. J.: Relationship of dentition to mental age. Ped. Sem. 33:387, 1926.

10. Cattell, R.: Dentition as a Measure of Maturity. (Monograph) Cambridge, Harvard University Press, 1928.

11. Steggerda, M.: Anthropometry and the eruption of teeth. J. Amer. Dent. Ass. 32:339, 1945.

12. Talmers, D. A.: Time of eruption of second permanent molar and relationship to body size and areolar development. New York Dent. J. 18:314, 1952.

13. Pittorru, Quirico: Relationship between tooth eruption and body growth in Sardinian school children. Dent. Abs. 1:484, 1956.

14. Garn, S. M. and Moorrees, C. F.: Stature, body build, and tooth emergence in Aleutian children. Child Develop. 22:262, 1951.

15. Demisch, A. and Wartmann, P.: Calcification of the mandibular third molar and its relation to skeletal and chronological age in children. Child Develop. 27:459, 1956.

16. Voors, A. W. and Metselaar, D.: The reliability of dental age as a yardstick to assess the unknown calendar age. Trop. Geogr. Med. 10:175, 1958.

17. Lamons, F. E. and Gray, S. W.: A study of the relationship between tooth eruption, skeletal developmental age, and chronological age in 61 Atlanta children. Amer. J. Orthodont. 44:687, 1958.

18. Binning, G.: Earlier physical and mental maturity among Saskatoon public school children. Canad. J. Public Health 49:9, 1958.

19. Garn, S. M., Lewis, A. B., Koski, K., and Polacheck, D. L.: The sex difference in tooth calcification. J. Dent. Res. 37:561, 1958.

20. Steel, G. H.: The relation between dental maturation and physiologic maturity. Dent. Pract. 16:23, 1965.

21. Gleiser, I. and Hunt, E. E. Jr.: The permanent mandibular first molar: Its calcification, eruption, and decay. Amer. J. Phys. Anthrop. 13:253, 1955.

22. Bambha, J. K. and Van Natta, Pearl: A longitudinal study of occlusion and tooth eruption in relation to skeletal maturation. Amer. J. Orthodont. 45:847, 1959.

23. Bayer, L. and Bayley, N.: Growth Diagnosis: Selected Methods for Interpreting and Predicting Physical Development from One Year to Maturity. Chicago, University of Chicago Press, 1959.

24. Hotz, R.: Relation of dental calcification to chronological age and skeletal age. Europ. Ortho. Soc. Trans. 35:140, 1959.

25. Hotz, R., Boulanger, B., and Weisshaupt, H.: Calcification time of permanent teeth in relation to chronological and skeletal age in children. Helv. Odont. Acta. 3:Number 1, 1959.

26. Lewis, A. B. and Garn, S. M.: Relationship between tooth formation and other maturational factors. Angle Orthodont. 30:70, 1960.

27. Nolla, C. M.: The development of the permanent teeth. J. Dent. Child. 27:254, 1960.

28. Sjunnesson, K.: Relation between eruption of permanent teeth and stage of mental development. Dent. Abs. 5:336, 1960.

29. Lauterstein, A. M.: A cross-sectional study in dental development and skeletal age. J. Amer. Med. Ass. 62:161, 1961.

30. Zannini, O.: Relation between chronological variation of dental eruption and somatogenic factors. Orthodont. Franc. 35:519, 8, 1964.

31. Skubiszewska, B.: Process of ossification in the hand and of second dentition as indicators of developmental age in children. Warsaw Instytut Matki I Dzibcka Prace I Materialy Naukowe. 1, 1963-1964.

32. Gibson, W. M., Vancouver, M. D., and Conchie, J. M.: Observation of children's teeth as a diagnostic aid: 1. Dentition in the assessment of development. J. Canad. Dent. Ass. 30:1, 1964.

33. Acheson, R. M. and Fowler, G. B.: Sex, socioeconomic status, and secular increase in stature: A family study. Brit. J. Prev. Soc. Med. 18:25, 1964.

34. Moorrees, C. F.: Dental development - A growth study based on tooth eruption as a measure of physiologic age. Europ. Ortho. Soc. 92, 1964.

35. Moorrees, C., Reed, R., and Chadha, J.: Growth changes of dentition defined in terms of chronologic and biologic age. Amer. J. Orthodont. 50:789, 1964. (abstract)

36. Fanning, Elizabeth A.: Some practical applications of research findings in tooth development. Aust. Dent. J. 9:374, 1964.

37. Steel, G. H.: A correlation study between dental and skeletal maturity. Europ. Ortho. Soc. 83, 1964.

38. Garn, S. M. and Lewis, A. B.: Genetic nutritional and maturational correlates of dental development. J. Dent. Res. 44:228, 1965.

39. Schwartz, S.: The validity of the human dentition as an indicator of physical maturity of boys ranging from 7 years to 12 years, 6 months of age. Ann Arbor, University Microfilms Inc., 1966.

40. Garn, S. M., Rohman, C. G., and Silverman, F. N.: Radiographic standards for postnatal ossification and tooth calcification. Med. Radiogr. Photogr. 43:45, 1967.

41. Wolanski, N.: A new method for the evaluation of tooth formation. Acta. Genet. (Basel) 16:186, 1966.

42. Kraus, B. S., Clark, G. R., and Oka, S. W.: Mental retardation and abnormalities of the dentition. Amer. J. Ment. Defic. 72:905, 1968.

43. Hiernaux, J.: Ethnic differences in growth and development. Eugen. Quart. 15:12, 1968.

44. Sinclair, D.: Human growth after birth. Oxford Medical Publications, 1969.

45. Schoen, E. J., Solomon, I. L., and Milkovich, L.: Bone age in short boys and tall girls. Amer. J. Dis. Child. 119:252, 1970.

46. Legoux, P. R.: Paleontologie humaine - Age dentaire de l'enfant neandertalien. Inform. Dent. 3:217, 1970.

47. Rosen, Leonard J.: Is permanent tooth eruption a criterion for school readiness? St. Louis, unpublished paper, 1970.

48. Kraske, L. M. and Mazzarella, M. A.: Evaluation of a panoramic dental X-ray machine. Dent. Prog. 1:171, 1961.

49. Updegrave, W. J.: Panoramic dental radiography. Dent. Radiogr. Photogr. 36:75, 1963.

50. Thorpe, J. O.: Panoramic radiography in the general practice of dentistry. Oral Surg. 24:781, 1967.

51. Guzman, C. A.: Principles and function of the Panoramix. Oral Surg. 24:196, 1967.

52. Kite, O. W., Swanson, L. T., Levin, S., and Bradbury, E.: Radiation and image distortion in Panorex X-ray unit. Oral Surg. 15:1201, 1962.

53. Mitchell, L. D. Jr.: Panoramic Roentgenography, a clinical evaluation. J. Amer. Dent. Ass. 66:777, 1963.

54. Graber, T. M.: Panoramic radiography in dentistry. J. Canad. Dent. Ass. 31:158, 1965.

55. Bruggemann, I. A.: Evaluation of the Panorex unit. Oral Surg. 24:348, 1967.

56. Christen, A. G. and Segreto, V. A.: Distortion and artifacts encountered in Panorex Radiography. J. Amer. Dent. Ass. 77:1096, 1968.

57. Yamani, G. M. and Biewald, K. H.: Image distortion in panoramic dental radiography. IADR reprinted abstracts 1968, p. 162 abstract #498.

58. Calonius, P. E. B.: Histologic criteria for age estimation of the developing human dentition. Oral Surg. 29:869, 1970.

59. Green, L. E. and Aszkler, S. E.: Intra-alveolar dental development in twins. J. Dent. Res. 49:631, 1970.

60. Gilbert, S. G.: Orthodontics and the Panorex dental X-ray. Bull. Phila. Dent. Soc. 28:11, 1962.

61. Kuba, R. K.: Radiation Dosimetry in Panorex Roentgenographic Examination. Thesis, Indiana University School of Dentistry, Indianapolis, 1966.

62. Reiss, Albert J. Jr.: "Occupations and Social Status." New York, The Free Press, 1961.

63. Moorrees, C. F., Fanning, Elizabeth A., and Hunt, E. E. Jr.: Age variation of formation stages for ten permanent teeth. J. Dent. Res. 42:1490, 1963.

CURRICULUM VITAE

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ABSTRACT

Dental Developmental Age Versus Chronological Age As Predictors Of Children's Functioning In Five Developmental Skills Areas

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The purpose of this study was to test the relationship between dental developmental age and chronologic age as they relate to other aspects of the child's development. The dental developmental age was determined on 74 children, 40 males and 34 females, ranging in age from two to 11 years. The sample population was chosen at random from patients at the Indiana University School of Dentistry. The socio-economic status was determined according to the North-Hatt Occupational Scale; 14.3 per cent of the children fell in the upper class, 84.3 per cent in the middle class, and 1.4 per cent in the lower class. Analysis by race showed that 71.6 per cent of the sample were Caucasian, 23.0 per cent were Negroid, and 5.4 per cent were Oriental. Panoramic radiography, with the S.S. White Panorex, was used to evaluate dental developmental age. Two independent observers scored the radiographs and double blind procedures were used. To determine dental developmental age, Wolanski's method of tooth formation evaluation was used. To determine functioning of children in five developmental skills areas, the Alpern-Boll Developmental Skills Inventory was used.

Dental developmental age and chronologic age had a significant positive relationship to children's functioning in five developmental skills areas. There is a chronologic period when determination of dental age appears to be difficult. The data available and methodology for determining dental developmental age of the four-year-old female and the five-year-old male seems to be inadequate.

Dental developmental age seems to be a better predictor of general developmental skills for males than it does for females, specifically in the two to eight-year-old group. The highest correlations were found in the youngest age group, i.e. the two to five-year-olds. The correlations between dental developmental age and chronologic age, and between those two indices and the five developmental skills ages remains highly significant in the younger ages but decreases consistently as the child becomes older. The specific age as well as the sex of the child has a definite effect on the correlations obtained.

The use of dental developmental age is good but not superior to the use of chronologic age for predicting functioning for normal children. This may not be the case for atypical children. More study is indicated.