A New System of Dental Age Assessment

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ABSTRACT

A new method is given for estimating dental maturity or dental age, by reference to the radiological appearances of the 7 teeth on the left side of the mandible. Panoramic radiographs of 1446 boys and 1482 girls of French Canadian parentage have been used. Each tooth has been rated according to developmental criteria (amount of dentinal deposit, shape change of the pulp chamber, etc.) rather than changes in size. Eight stages, A to H, have been defined from the first appearance of calcified points to the closure of the apex. The method of Tanner, Whitehouse and Healy for skeletal maturity has been used for deriving a score for each stage of each tooth. The summed scores on all seven teeth give a dental maturity score which can be converted directly into a dental age. In case of missing teeth, the possibility of using combinations of different teeth is discussed.

Although the maturity scoring system is probably universal in application, the conversion to dental age, or the location of the centiles for maturity at given ages, depends on the population considered. The present system is applicable from age 3 to 17; we hope to extend it to younger ages as material accumulates.

The concept of physiological age is based upon the degree of maturation of different tissue systems. Several biological ages have been developed: skeletal age, morphological age, secondary sex character age and dental age. These criteria can be applied separately or together to assess the degree of physiological maturity of a growing child.

Dental age is of particular interest to the orthodontist in planning the treatment of different types of malocclusions in relation to maxillo-

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facial growth. It can also be a help in determining the age of cadavers or in skeletal material where other parts of the body are missing. In pediatric endocrinopathies the diagnosis and the results of treatment may sometimes be better evaluated if dental age is assessed in parallel with other maturity indicators.

Until quite recently, clinical eruption has been the only criterion used for dental maturity or dental age (Bean 1914; Beik 1913 and Cateli 1928). Norms derived from Logan and Kronfeld's data (1933), as modified by Schour and Massler (1940), as well as from Hurme's (1949) and Clements, Davies-Thomas and Pickett's (1957) data have been used extensively.

The timing of eruption of the permanent teeth in relation to race and sex has been studied by several authors (Carr 1962; Clements et al. 1957; Dahlberg and Maunsbach 1948-50; Halikis 1961; Houpt et al. 1967; Hurme 1949; Knott and Meredith 1966; Nanda 1960; Steggerda and Hill 1942; Stones et al. 1951). Different criteria have been used for in the appendix (Figure 1). There are eight stages, A to H, for each tooth together with stage 0 for non-appearance.

Gingival emergence, which is often erroneously called eruption, represents only one stage in the continuous process of dental eruption, or migration to reach the occlusal level. Emergence may be influenced by local factors: ankylosis, early or delayed extraction of the deciduous tooth, impaction and crowding of the permanent teeth (Fanning 1961; McDonald 1969; Posen, 1965). In contrast, formation rate of the permanent teeth is not affected by premature loss of the deciduous teeth (Fanning 1962; Sapoka and Demirjian 1971). Furthermore if clinical emergence is used as the criterion for dental age assessment, it can only be applied up to the age of 30 months (completion of the deciduous dentition) and after the age of 6 years (eruption of the first molar).

Several authors have investigated the association between emergence and root formation (Brauer and Bahador 1942; Garn and Lewis 1957; Gleiser and Hunt 1955; Grøn 1962; Haavikko 1970; Shumaker and El Hadary 1960). Different definitions of formation and "eruption" have been used. Visible emergence usually occurs when root formation is about three quarters completed, but quite large departures from this rule have been observed. Furthermore, the association between emergence and formation varies between different teeth. Recently Liliequist and Lundberg (1971) have investigated a scoring system for maturity, and Fanning (1971) has initiated a multivariate analysis approach.

These studies have led to the conclusion that tooth formation is a more reliable indicator of dental maturity than gingival emergence or "eruption."

The Construction of a Maturity Scale

In order to study dental formation, different developmental stages have been defined by several authors (Fanning 1961; Garn and Lewis 1957; Gleiser and Hunt 1955; Moorrees et al. 1963; Nolla 1960). These stages have usually been marked by recognisable tooth shapes, from the beginning of calcification through to final mature form. Useful stages must be easily recognisable, and such that a tooth always passes through the same stages in every individual. Since the stages are indicators of maturity and not of size they cannot be defined by any absolute length measurements. After study of both longitudinal and cross-sectional material we have adopted the stages described and illustrated in the appendix (Figure 1). There are eight stages, A to H, for each tooth together with stage O for non-appearance.

The purpose of the present study is to derive a method of estimating overall dental maturity or dental age, by a quantity based on the stages observed in each tooth. This problem occurs in defining any other kind of maturity, for example skeletal maturity based on the bones of the hand and wrist. Two general approaches have been advocated. One of these, the Atlas approach (Greulich and Pyle 1959) sets out a typical "profile" of stages at each of a series of ages over the age range being studied. Any new set of ratings is then compared with these profiles until the best matching one is found, and the corresponding age then becomes the estimate of skeletal or dental age. The other approach (Tanner, Whitehouse and Healy 1962) is to give each bone, or tooth, a score depending on its stage. The scores on all the teeth are then added together to give a total maturity score which can be converted directly into a dental age using an appropriate table of standards. A method for deriving the scores and its justification is described in Tanner et al. (1962) in relation to skeletal age. It is this method which we have adopted. A relatively minor methodological revision has recently been made in this technique (Tanner et al. 1973) and we have used this revised form. In it the final scores for each tooth, previously constrained each to be 100, are allowed to vary so that only their sum (or average) over all the teeth is 100. This makes allowance for the different ages at

which different teeth reach maturity. Girls and boys are given different systems of scores.

Material and Methods

The data (Table 1) consist of panoramic radiographs of the teeth of 1446 boys and 1482 girls aged 2 to 20, examined in the Ste-Justine Hospital and the Growth Centre, Montreal (Demirjian et al. 1971). We took radiographs only from children free from any disorder affecting growth and who had a complete mandibular permanent dentition (erupted or not). All had parents and grand-parents of French Canadian origin.

Table 1

Number of Children at Each Age

Age	Boys	Girls	Total
2.0- 3.5	44	33	77
- 4.5	58	46	104
- 5.5	63	59	122
- 6.5	117	117	234
- 7.5	108	100	208
- 8.5	105	111	216
- 9.5	143	167	310
-10.5	222	209	431
-11.5	114	120	234
-12.5	99	80	179
-13.5	122	111	233
-14.5	142	164	306
-15.5	69	96	165
-20.0	40	69	109
TOTAL	1446	1482	2928

Panoramic radiographs were used because they are easier to make than intraoral radiographs in young or nervous children; they give less radiation for a full mouth radiograph (McDonald 1969) and the picture of the mandibular region they produce is little distorted. Though there is 3 to 10% enlargement on the left side of the mandible (Sapoka and Demirjian 1971) this is not a serious drawback, because our rating system is based on shape criteria and relative values rather than on absolute lengths.

The radiographs were rated by four examiners all trained by one of them. Each examiner rated the same percentage of radiographs of each age group. At the end of each day, five randomly chosen X-rays were reassessed by each examiner, results were compared and any discrepancies were discussed. Disagreement between examiners occurred in no more than 10% of films and was never more than one stage.

Results

The analysis of the individuals' ratings, in the manner described by Tanner et al. (1973) led to the maturity scores given in Table 2 (in appendix). Girls and boys were treated separately, because this allows for sex-tooth interaction, that is for one tooth being relatively more advanced in one sex than in the other. This is known to occur in tooth eruption, and appears also in our scores, since they are higher for girls than boys in all teeth except M1 where girls are lower.

The analysis gives a set of scores, one for each stage of each tooth (Table 2). These are then added together for a particular individual set, to give a maturity score for that individual. This maturity score is then referred to the centile chart or to Table 3 (in appendix) for conversion to a dental age. (See Appendix for details).

The centile curves (Figures 2 and 3) have been plotted exponentially, since this scale leads to better visual presentation than a linear scale. Though not symmetrical at either end, the centile lines still have a visible space between them, rather than converging to a tiny area as they would in a linear presentation. The centile distribution is symmetrical at about age 7½ in both sexes.

Discussion

In one sense the results presented here are preliminary ones, because the full range from immaturity to maturity is not covered. Among the youngest groups of children there are insufficient numbers to provide accurate estimates of maturity centiles and dental age, although the numbers are sufficient to provide good estimates of the maturity scores. Thus the centile charts only run from three to seventeen years and it is intended to extend them when data become available.

We initially used all fourteen lower mandibular teeth in the scoring system. It is well known however that a very high degree of symmetry exists between the left and right side teeth, and we therefore investi-

gated whether a seven tooth system using one side only would give almost the same estimate as one using all fourteen teeth. We calculated separate fourteen and seven tooth systems, the seven teeth being taken from the left side. For each child we estimated the dental age on each system and then took the difference in dental ages between the two systems. Perfect agreement between the systems would be indicated by a constant difference at each age. The variation of the difference can be used as a measure of how much the systems differ. The standard deviation of the difference between fourteen and seven tooth systems was small, being about three weeks at eight years of age, compared to a standard deviation of the dental age on either system of about six months. It thus appears that the seven tooth system is acceptable and we have used the seven teeth on the left side as the basis of our system.

In the bone age system different "biological" weights are attached to the bones so as to allow for the three phalanges in a finger giving very similar information, and swamping, for example, the metacarpal (Tanner et al. 1973). We have tried several "biological" weighting systems of this sort and find that they make very little difference to the resulting estimates. The standard deviation of the differences in dental ages are about the same as that found between the fourteen tooth and seven tooth systems. For simplicity we have therefore given each tooth equal weight.

In contrast to the situation in the bones of the hand and wrist, a particular child may have one or more teeth missing. The question then arises as to whether the remaining teeth may be used to give a maturity estimate. Where the teeth corresponding to those missing are present on the right side of the lower mandible they may be simply substituted. Where this is not the case, however, there are two possible approaches. Either we may try to "estimate" a score for the missing tooth or we may use a scoring system based only on those teeth present.

The first possibility is unsatisfactory for the following reasons. If, for example, just one tooth is missing we could attempt to estimate it by inserting the average score over the other six teeth. If the missing tooth always tends to be the same one, this procedure will lead to a biased estimate at any particular age. If teeth are missing uniformly at random, then although the maturity score estimate will be unbiased, the variability will be greater than the corresponding score based on seven teeth, so that the seven tooth centile limits will be too narrow.

The second method avoids these drawbacks, but it does imply that a separate system has to be calculated and published for each combina-

tion of less than seven teeth. However, it might be practicable to do this for some of the most commonly found combinations. We have therefore investigated the six tooth system obtained by missing out the first molar. Using the same measure of difference as before, we find that at age eight, the standard deviation of the difference in dental age between the two systems is as much as five weeks. It therefore seems questionable as to whether the two systems are in fact estimating the same thing. By leaving out a tooth we may be measuring a slightly different aspect of maturity. This, taken along with the difficulty of supplying separate systems for all the most common combinations has led us to abandon the attempt for the time being. However, as more data accumulate we do intend to pursue this problem further.

We have similarly studied 4-tooth systems (M_2, M_1, Pm_2, Pm_1 and M_2, Pm_2, Pm_1, I_1) which form a convenient group of teeth for rating purposes. We find, at age eight, a standard deviation of the difference in dental ages of about ten weeks, and at higher ages, the distribution also tends to become bimodal.

In using the maturity standards given in Table 3 of this paper, it should be remembered that the sample on which they are based is entirely of French Canadian origin. The dental maturity scores for given chronological age may well be greater or less in other populations, according as to whether they are more or less dentally advanced during growth.

It seems reasonable to assume however, that the pattern of development of the teeth will not vary very much in different populations, so that the scores of Table 2 for the stages should be similar in other populations. The differences will arise only when these are converted to a dental age. We therefore recommend our maturity scoring system as a valid measuring instrument for universal use. Furthermore, with the use of relatively small local samples, and by comparison with our Table 3, dental age equivalents could readily be estimated for different populations.

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APPENDIX

Assigning the Ratings

1. The mandibular permanent teeth are rated in the following order: 2nd molar, 1st molar, 2nd bicuspid, 1st bicuspid, canine, lateral incisor, central incisor.

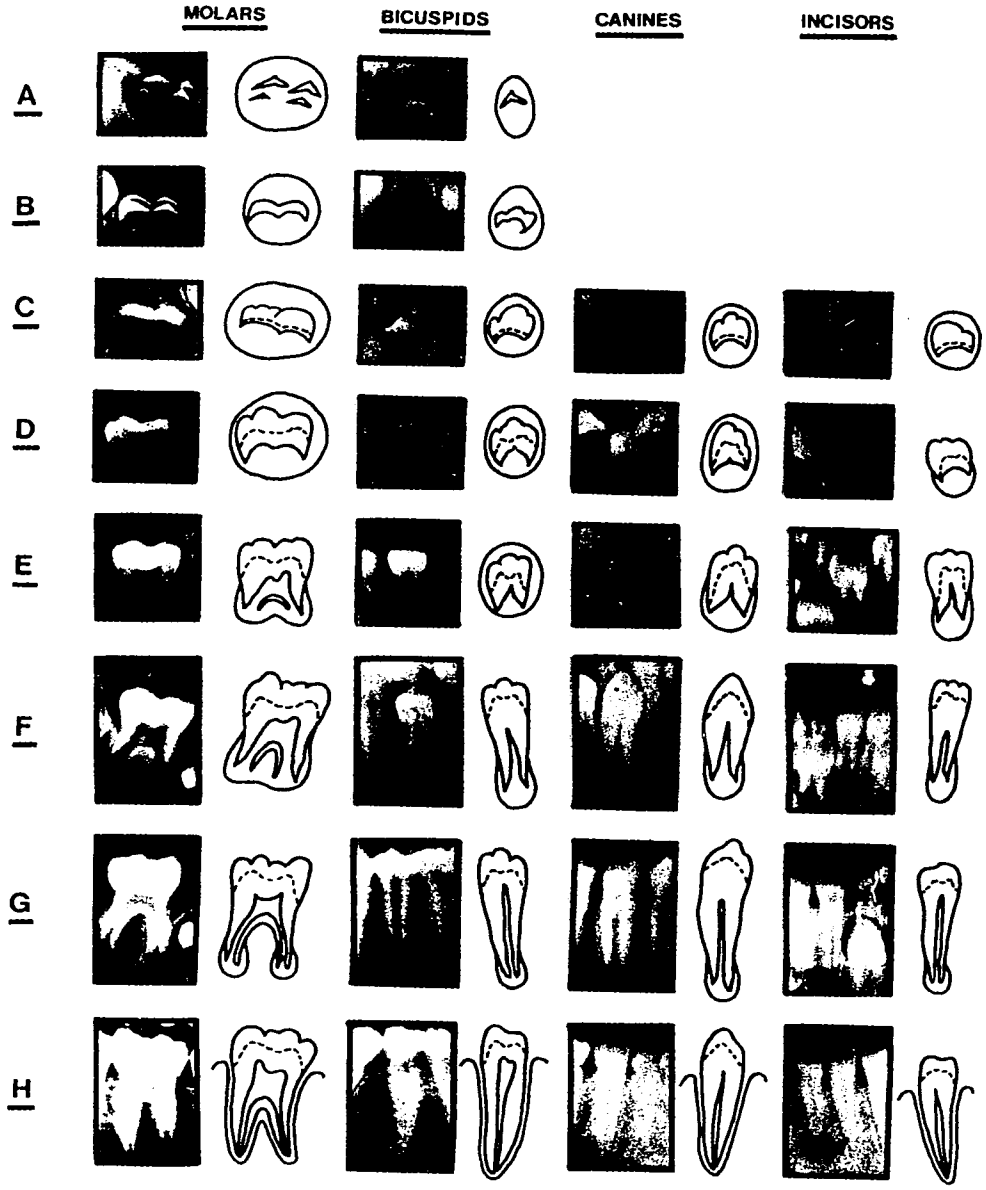

FIG. 1. Developmental stages of the permanent dentition.

2. All teeth are rated on a scale A to H. The rating is assigned by following carefully the written criteria for each stage, and by comparing the tooth with the diagrams and Xray pictures given in Figure 1. The illustrations should only be used as an aid, not as the sole source

of comparison. For each stage there are one, two or three written criteria marked a), b), c). If only one criterion is given this must be met for the stage to be taken as reached; if two criteria are given, then it is sufficient if the first one of them is met for the stage to be recorded as reached; if three criteria are given, the first two of them must be met for the stage to be considered reached. At each stage, in addition to the criteria for that stage, the criteria for the *previous* stage must be satisfied. In borderline cases the earlier stage is always assigned.

3. There are no absolute measurements to be taken. A pair of dividers is sufficient to compare the relative length (crown/root). To determine apex closure stages no magnifying glass is necessary. The ratings should be made with the naked eye.
4. The crown height is defined as being the maximum distance between the highest tip of the cusps and the cemento-enamel junction. When the buccal and lingual cusps are not at the same level, the midpoint between them is considered as the highest point.

Dental Formation Stages

If there is no sign of calcification, the rating 0 is given: The crypt formation is not taken into consideration.

STAGE	*DESCRIPTION*
A	In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.
B	Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface.
C	a. Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen. b. The beginning of a dentinal deposit is seen. c. The outline of the pulp chamber has a curved shape at the occlusal border.
D	a. The crown formation is completed down to the cemento-enamel junction. b. The superior border of the pulp chamber in the uniradicular teeth has a definite curved form, being concave towards the cervical region. The projection of the pulp

horns if present, gives an outline shaped like an umbrella top. In molars the pulp chamber has a trapezoidal form.

c. Beginning of root formation is seen in the form of a spicule.

E *Uniradicular teeth:*

a. The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in the previous stage.

b. The root length is less than the crown height.

Molars:

a. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semi-lunar shape.

b. The root length is still less than the crown height.

Table 2 (Appendix)

Self-Weighted Scores for Dental Stages 7 Teeth (Mandibular Left Side)

	Boys								
	Stage								
Tooth	0	A	B	C	D	E	F	G	H
M_2	0.0	2.1	3.5	5.9	10.1	12.5	13.2	13.6	15.4
M_1				0.0	8.0	9.6	12.3	17.0	19.3
PM_2	0.0	1.7	3.1	5.4	9.7	12.0	12.8	13.2	14.4
PM_1			0.0	3.4	7.0	11.0	12.3	12.7	13.5
C				0.0	3.5	7.9	10.0	11.0	11.9
I_2				0.0	3.2	5.2	7.8	11.7	13.7
I_1					0.0	1.9	4.1	8.2	11.8
	Girls								
	Stage								
Tooth	0	A	B	C	D	E	F	G	H
M_2	0.0	2.7	3.9	6.9	11.1	13.5	14.2	14.5	15.6
M_1				0.0	4.5	6.2	9.0	14.0	16.2
PM_2	0.0	1.8	3.4	6.5	10.6	12.7	13.5	13.8	14.6
PM_1			0.0	3.7	7.5	11.8	13.1	13.4	14.1
C				0.0	3.8	7.3	10.3	11.6	12.4
I_2				0.0	3.2	5.6	8.0	12.2	14.2
I_1					0.0	2.4	5.1	9.3	12.9

NB: Stage 0 is no calcification

F *Uniradicular teeth:*

a. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape.

b. The root length is equal to or greater than the crown height.

Molars:

a. The calcified region of the bifurcation has developed further down from its semi-lunar stage to give the roots a more definite and distinct outline with funnel shaped endings.

b. The root length is equal to or greater than the crown height.

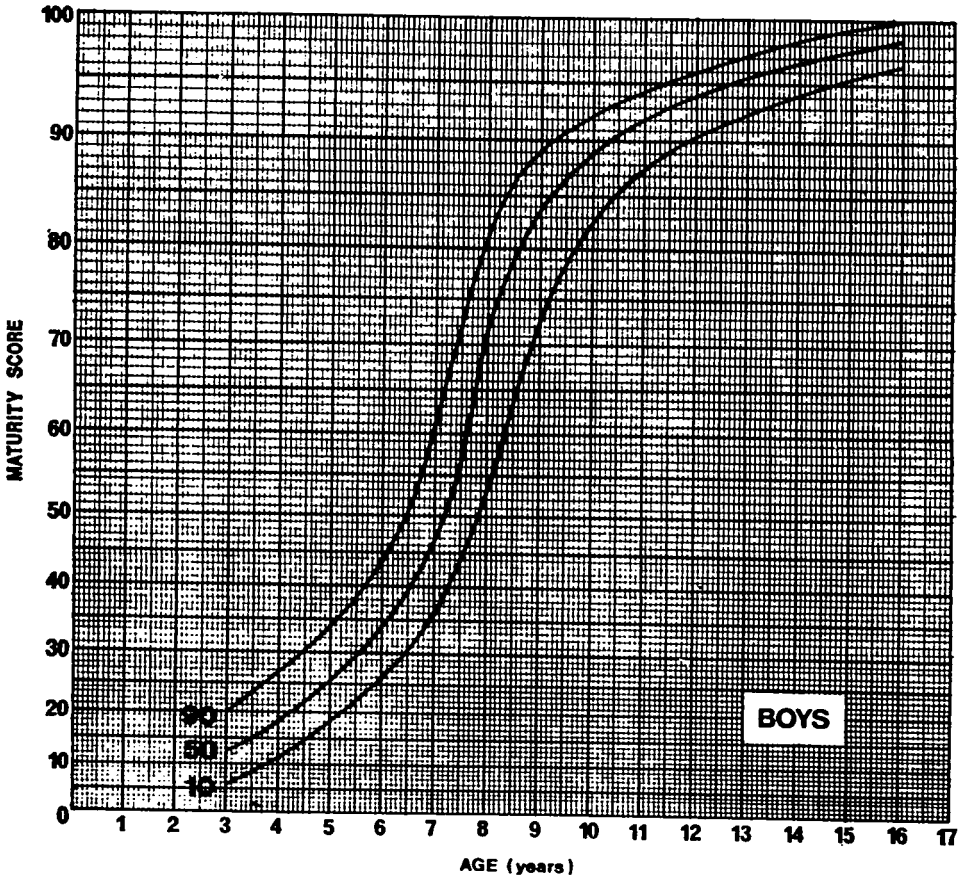

FIG. 2. Dental maturity percentiles (7 teeth).

Table 3

Conversion of Maturity Score to Dental Age (7 Teeth)

Age	Score	Age	Score	Age	Score	Age	Score
				Boys			
3.0	12.4	7.0	46.7	11.0	92.0	15.0	97.6
.1	12.9	.1	48.3	.1	92.2	.1	97.7
.2	13.5	.2	50.0	.2	92.5	.2	97.8
.3	14.0	.3	52.0	.3	92.7	.3	97.8
.4	14.5	.4	54.3	.4	92.9	.4	97.9
.5	15.0	.5	56.8	.5	93.1	.5	98.0
.6	15.6	.6	59.6	.6	93.3	.6	98.1
.7	16.2	.7	62.5	.7	93.5	.7	98.2
.8	17.0	.8	66.0	.8	93.7	.8	98.2
.9	17.6	.9	69.0	.9	93.9	.9	98.3
4.0	18.2	8.0	71.6	12.0	94.0	16.0	98.4
.1	18.9	.1	73.5	.1	94.2		
.2	19.7	.2	75.1	.2	94.4		
.3	20.4	.3	76.4	.3	94.5		
.4	21.0	.4	77.7	.4	94.6		
.5	21.7	.5	79.0	.5	94.8		
.6	22.4	.6	80.2	.6	95.0		
.7	23.1	.7	81.2	.7	95.1		
.8	23.8	.8	82.0	.8	95.2		
.9	24.6	.9	82.8	.9	95.4		
5.0	25.4	9.0	83.6	13.0	95.6		
.1	26.2	.1	84.3	.1	95.7		
.2	27.0	.2	85.0	.2	95.8		
.3	27.8	.3	85.6	.3	95.9		
.4	28.6	.4	86.2	.4	96.0		
.5	29.5	.5	86.7	.5	96.1		
.6	30.3	.6	87.2	.6	96.2		
.7	31.1	.7	87.7	.7	96.3		
.8	31.8	.8	88.2	.8	96.4		
.9	32.6	.9	88.6	.9	96.5		
6.0	33.6	10.0	89.0	14.0	96.6		
.1	34.7	.1	89.3	.1	96.7		
.2	35.8	.2	89.7	.2	96.8		
.3	36.9	.3	90.0	.3	96.9		
.4	38.0	.4	90.3	.4	97.0		
.5	39.2	.5	90.6	.5	97.1		
.6	40.6	.6	91.0	.6	97.2		
.7	42.0	.7	91.3	.7	97.3		
.8	43.6	.8	91.6	.8	97.4		
.9	45.1	.9	91.8	.9	97.5		

Table 3 (continued)

Conversion of Maturity Score to Dental Age 7 Teeth (Mandibular Left Side)

Age	Score	Age	Score	Age	Score	Age	Score
				Girls			
3.0	13.7	7.0	51.0	11.0	94.5	15.0	99.2
.1	14.4	.1	52.9	.1	94.7	.1	99.3
.2	15.1	.2	55.5	.2	94.9	.2	99.4
.3	15.8	.3	57.8	.3	95.1	.3	99.4
.4	16.6	.4	61.0	.4	95.3	.4	99.5
.5	17.3	.5	65.0	.5	95.4	.5	99.6
.6	18.0	.6	68.0	.6	95.6	.6	99.6
.7	18.8	.7	71.8	.7	95.8	.7	99.7
.8	19.5	.8	75.0	.8	96.0	.8	99.8
.9	20.3	.9	77.0	.9	96.2	.9	99.9
4.0	21.0	8.0	78.8	12.0	96.3	16.0	100.0
.1	21.8	.1	80.2	.1	96.4		
.2	22.5	.2	81.2	.2	96.5		
.3	23.2	.3	82.2	.3	96.6		
.4	24.0	.4	83.1	.4	96.7		
.5	24.8	.5	84.0	.5	96.8		
.6	25.6	.6	84.8	.6	96.9		
.7	26.4	.7	85.3	.7	97.0		
.8	27.2	.8	86.1	.8	97.1		
.9	28.0	.9	86.7	.9	97.2		
5.0	28.9	9.0	87.2	13.0	97.3		
.1	29.7	.1	87.8	.1	97.4		
.2	30.5	.2	88.3	.2	97.5		
.3	31.3	.3	88.8	.3	97.6		
.4	32.1	.4	89.3	.4	97.7		
.5	33.0	.5	89.8	.5	97.8		
.6	34.0	.6	90.2	.6	98.0		
.7	35.0	.7	90.7	.7	98.1		
.8	36.0	.8	91.1	.8	98.2		
.9	37.0	.9	91.4	.9	98.3		
6.0	38.0	10.0	91.8	14.0	98.3		
.1	39.1	.1	92.1	.1	98.4		
.2	40.2	.2	92.3	.2	98.5		
.3	41.3	.3	92.6	.3	98.6		
.4	42.5	.4	92.9	.4	98.7		
.5	43.9	.5	93.2	.5	98.8		
.6	45.2	.6	93.5	.6	98.9		
.7	46.7	.7	93.7	.7	99.0		
.8	48.0	.8	94.0	.8	99.1		
.9	49.5	.9	94.2	.9	99.1		

G a. The walls of the root canal are now parallel and its apical end is still partially open (Distal root in molars).

H a. The apical end of the root canal is completely closed. (Distal root in molars).

b. The periodontal membrane has a uniform width around the root and the apex.

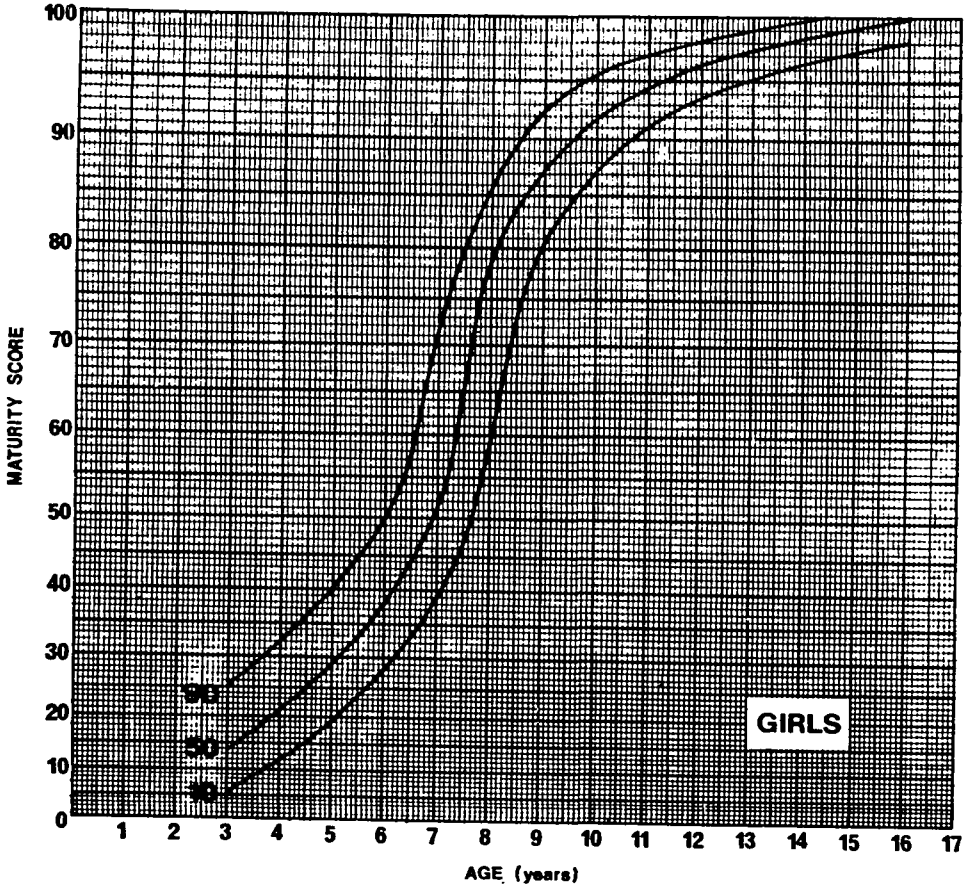

FIG. 3. Dental maturity percentiles (7 teeth).

Using the Scoring System

1. Each tooth will have a rating, assessed by the procedure described.
2. This is converted into a score using Table 2 for boys or girls as appropriate. For example if tooth M_1 of a boy is in stage E it is given a score 9.7.

3. The scores for all seven teeth are added together to give the *maturity score.*
4. The maturity score may be plotted on the centile charts (boys or girls as appropriate) where the age of the child is known. For example a score of 35 for a boy aged 5.0 years lies just above the 90th centile.
5. The maturity score may be converted directly into a dental age either by reading off on the horizontal scale the age at which the 50th centile attains that maturity score value, or by using Table 3 which has been constructed by this means. Thus a score of 45 for a boy is equivalent to a dental age of 6.9 years.