Assessment of Dental and Skeletal Maturity

A New Approach

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A comparison of radiographic methods of assessing skeletal and dental maturation, and an evaluation of the the correlations among the various maturity indicators in the 8-12 year age range.

KEY WORDS: • DENTAL AGE • MATURATION • SKELETAL MATURATION • RADIOLOGY •

Many researchers have attempted to determine whether there is a relationship between the level of skeletal maturity (skeletal age) and the maturation of the permanent dentition. The data reported in the literature, however, has presented rather inconclusive results. DEMISCH AND WARTMANN (1956) report a high correlation between dental and skeletal ages, and LILLIEQUIST AND LUNDBERG (1971), report similar correlations. ACHESON AND DUPERTUIS (1957), LEWIS AND GARN (1959), AND TANNER (1962), on the other hand, have reported low or insignificant correlations between the level of skeletal maturation and dental eruption. The lack of concordance among the results of previous studies may be due, at least in part, to the different methods of assessing skeletal and dental maturity.

It has long been contended that dental eruption, which is the most conspicuous and easily determined indicator of dental maturation, is much more variable in its timing than skeletal maturation (BRADY 1924, NOLLA 1960, VAN DER LINDEN 1979). Dental eruption has also been reported to be more variable than the calcification sequence in the dentition (NOLLA 1960).

Conceivably, the low degree of correlation observed between skeletal maturation and dental eruption or dental calcification in some studies is due to the fact that many of the centers of ossification in the hand exhibit considerable variation in the timing of their onset. So it may be argued that attention should be focused on those ossific centers that are least variable in the timing of their onset. Such an approach could reveal a degree of association not readily apparent when the maturation of the hand and wrist are assessed in an overall fashion, as with the Todd Inspectional Method (TIM).

The purpose of this investigation is to evaluate the correlations between the developmental stages of those individual ossific centers that exhibit the least

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variability in their onset of ossification, and the calcification of the upper and lower cuspids, bicuspids, and second molars in the permanent dentition. Additionally, the results are compared using both the TIM and the Ossific Center Method (OCM), which is based on a limited number of bony centers.

If a close relationship exists between the two developmental phenomena tested here, the level of calcification of the permanent teeth could be used more effectively in estimating the level of skeletal development in our patients.

— Methods and Materials —

Subjects of this investigation were 153 orthodontically treated Caucasian children ranging in age from 8 through 12 years, selected from the case records of the Department of Orthodontics at the University of Detroit School of Dentistry. Distribution by sex and age is shown in Table 1.

Treatment records included a pretreatment hand-wrist radiograph and a Panelipse radiograph, using a fixed object-film distance on the same machine.

The teeth selected for study were the permanent upper and lower cuspids, the first and second bicuspids, and the second molars. These teeth were selected because their period of formation corresponded with the age range of the subjects in this study.

The panographs were used to determine the stage of development of the teeth on the left side of each subject, according to Nolla (1960) (Fig. 1). In this procedure, the developmental stage of each tooth is compared to a series of standardized drawings depicting 10 stages of tooth calcification. As recommended by Nolla, for those subjects where the development of a tooth was found to lie between two stages, a half-value was assigned.

A comparable procedure was used for the hand-wrist films, based on the maturity indicators for the individual bones developed by Greulich and Pyle (1959) (Figs. 2 and 3).

The stages listed in the maturity indicator section of the Greulich and Pyle Atlas are conceptually comparable to the Nolla dental classification. This procedure represents a departure from the conventional usage of the Greulich and Pyle Atlas, in which skeletal age is determined

Table 1

Distribution of Subjects by Age and Sex

Group	Age (months)	Males	Females	Total
1	91- 96	4	6	10
2	97-102	3	3	6
3	103-108	9	11	20
4	109-114	11	8	19
5	115-120	10	9	19
6	121-126	10	4	14
7	127-132	4	11	15
8	133-138	7	8	15
9	139-144	11	13	24
10	145-150	3	8	11
Total		72	81	153

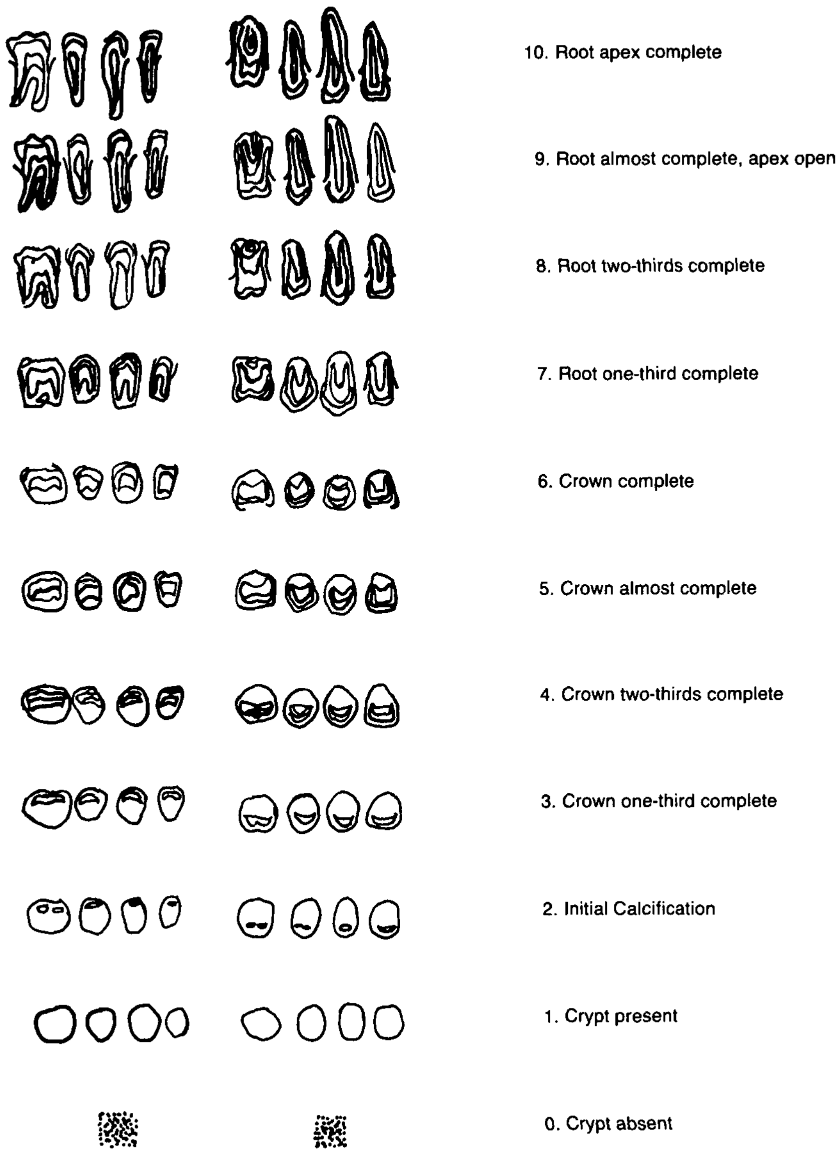


Fig. 1 **Stages of tooth calcification.** *(From Nolla, 1960, with permission)*

V

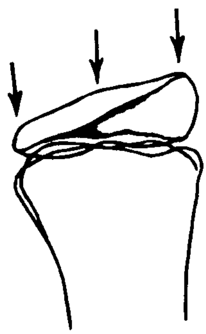
The epiphysis has elongated transversely. The white outline of the volar margin of the epiphysis is now distinct as it extends laterally from the ulnar tip along the inner bone margin of the epiphysis beyond the center of the shaft.

VI

Along the ulnar tip, the distal margin of the epiphysis is slightly flattened as its lunate and ulnar articular facets begin to differentiate.

VII

That portion of the epiphysis from which the styloid process develops begins to enlarge. The central arrow points to the approximate center of the distal articular surface of the radius. The original ossification center, according to its alignment with the lateral side of the capitate, forms beneath the approximate center of this epiphyseal articular surface.



VIII

The epiphysis is now as wide as the adjacent margin of the diaphysis. The styloid process, which requires a period of years for its full development, is now well formed.

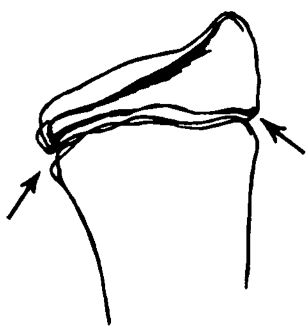
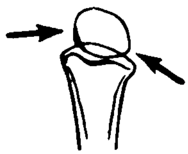


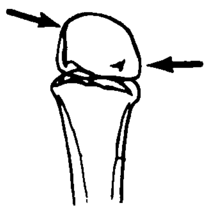
Fig. 2 Selectedtages of ossification of the distal end of the radius.

(from Greulich and Pyle, 1959, with permission)



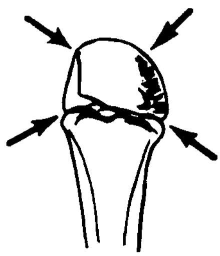
V

The radial, ulnar, and distal margins of the epiphysis have become dissimilar in shape as the joint surface begins to differentiate.



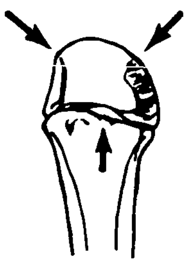
VI

Parts of the volar surface of the epiphysis are now visible as thin, white linear markings just within its radial and ulnar margins.



VII

The epiphysis is now as wide as the distal end of the diaphysis, and their adjacent margins conform closely in shape. There is as yet no reduction in the thickness of the growth cartilage plate.



VIII

Epiphyseal-diaphyseal fusion begins.

IX

The epiphysis has recently fused with its shaft.

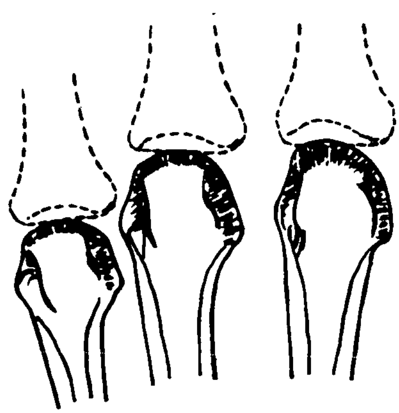


Fig. 3 Selected stages of ossification of the 2nd and 3rd metacarpals.
(From Greulich and Pyle, 1959, with permission)

on a sliding scale by matching the 30 bones in the hand and wrist, assigning an age to each bone, and then averaging those 30 ages to give a single age.

Thus, the skeletal and dental age determinations introduced here provide two scales that come closer to treating the developmental events as discrete stages.

In addition, a determination of overall skeletal age for the entire hand-wrist was made using the conventional Todd inspection method of skeletal assessment. This compares the status of the hand-wrist radiograph with the half-tone plates in the Atlas to select the most appropriate match.

The eight ossific centers assessed in this investigation were selected because they exhibit the least variability in timing of the onset of ossification, as indicated in Table I (Onset of Ossification) in the Greulich and Pyle Atlas. The ossific centers studied were: the epiphyses of the proximal phalanges of the 2nd, 3rd, 4th, and 5th fingers, the epiphysis of the 2nd and 3rd metacarpals, the epiphysis of the middle phalanx of the 4th finger, and the epiphysis at the distal end of the radius. Following conventional practice, all assessments were made on the left hand.

Developmental stages of these epiphyses are shown in Fig. 2 and 3.

Examination of the standard deviation for the time of onset of ossification indicated that the same eight bones could be used for both boys and girls (Greulich and Pyle 1959). In order to determine whether the timing of onset of growth for the eight centers of ossification was sequenced similarly in boys and girls, a Spearman rank-order correlation was performed. The r value obtained was 0.88, indicating essential comparibility for the two sequences.

In the data tables, the following symbols are used to designate the ossific centers and teeth. The listing below shows the variability rank for males, with the variability rank for females in parentheses.

Bones

1 (4) pp3 = epiphysis of the proximal phalanx, 3rd finger
2 (1) pp2 = epiphysis of the proximal phalanx, 2nd finger
3 (2) pp4 = epiphysis of the proximal phalanx, 4th finger
4 (3) M2 = epiphysis of the 2nd metacarpal
5 (6) pp5 = epiphysis of the proximal phalanx, 5th finger
6 (5) M3 = epiphysis of the 3rd metacarpal
7 (7) dr = epiphysis at the distal end of the radius
8 (8) mp4 = epiphysis of the middle phalanx, 4th finger.

Teeth

U3 = upper cuspid
U4 = upper first bicuspid
U5 = upper second bicuspid
U7 = upper second molar
L3 = lower cuspid
L4 = lower first bicuspid
L5 = lower second bicuspid
L7 = lower second molar

All of the assessments were made by one examiner. In order to determine observer replicability, 20 subjects, 10 males and 10 females, were evaluated a second time after a lapse of several weeks. A Student's "t" test for matched pairs indicated that the error of measurement was extremely low, with the largest "t" value 0.210 ($p=0.84$).

— Results —

Spearman rank-order correlation coefficient (r) of the developmental stages for each of the eight ossific centers with the comparative stages of development of the eight individual teeth are shown in Tables 2 through 4. For the sexes combined, the highest correlations were obtained for the lower cuspid (L3), and were in the order of 0.7 to 0.8.

It is noteworthy that the lower cuspid correlated better with each of the eight ossific centers than any of the other seven teeth studied (Table 2).

Tables 3 and 4 show the intercorrelations between the stages of dental development and skeletal maturation for males and females, respectively. Again, the correlations are relatively high and with few exceptions, the lower cuspid (L3) shows the highest correlation with each of the ossific centers.

In Tables 2 through 4, the bones and teeth are arranged in order from the highest to the lowest correlation. For the males, only 4 of the 64 intercorrelations depart from this pattern. For the females, only 2 of the intercorrelations are higher for some tooth other than the lower cuspid. The upper first bicuspid (U4) was the tooth showing the highest correlation in 4 of those 6 deviations.

Table 2

Rank-ordered (R1 × C1) intercorrelations
of developmental stages
of 8 ossific centers with 8 teeth
bones and teeth arranged from highest to lowest correlation
based on Greulich and Pyle and Nolla's stages
(both sexes)

	Ossific Center							
Tooth	Dr	M2	M3	pp4	pp3	pp5	pp2	mp4
L3	.81	.81	.81	.80	.80	.79	.77	.75
U3	.79	.78	.78	.77	.77	.75	.76	.73
U4	.79	.77	.77	.75	.74	.72	.73	.69
L4	.77	.74	.74	.74	.73	.71	.72	.68
L7	.77	.73	.73	.74	.73	.71	.71	.66
U7	.74	.70	.70	.70	.70	.68	.68	.62
U5	.74	.70	.70	.68	.67	.66	.66	.62
L5	.74	.69	.69	.69	.68	.66	.67	.63

Table 3

Rank-ordered (R1 × C1) intercorrelations
of developmental stages
(Males)

	Ossific Center							
Tooth	M3	M2	pp3	Dr	pp4	pp5	pp2	mp4
L3	.82	.82	.78	.76	.76	.76	.70	.67
U4	.79	.79	.76	.78	.75	.69	.73	.65
U3	.79	.79	.76	.74	.74	.71	.73	.66
L7	.75	.75	.74	.72	.76	.71	.70	.64
L4	.75	.75	.70	.70	.69	.64	.66	.60
L5	.74	.74	.70	.73	.70	.65	.68	.62
U7	.72	.72	.71	.68	.72	.68	.66	.61
U5	.72	.72	.69	.73	.69	.63	.65	.60

Table 4

Rank-ordered (R1×C1) intercorrelations of developmental stages (Females)

Tooth	Dr	mp4	pp4	Ossific Center pp2	pp5	pp3	M2	M3
L3	.81	.81	.80	.79	.79	.78	.77	.77
U4	.81	.80	.80	.78	.78	.78	.78	.78
U7	.81	.75	.78	.77	.77	.78	.76	.76
U3	.80	.80	.79	.78	.77	.78	.75	.75
L4	.80	.78	.78	.76	.76	.76	.72	.72
U5	.78	.75	.77	.75	.75	.75	.76	.76
L7	.78	.73	.73	.72	.72	.73	.72	.72
L5	.76	.70	.72	.69	.70	.70	.67	.67

Although the sequence of the onset of ossification for the eight ossific centers is quite similar for the males and females (r=0.88), when the individual centers are correlated by sex with such variables as dental age and chronological age, that order is dramatically different for the two sexes. These differences in sequence are significant, as indicated by an r value of −.70, suggesting that in the females one should look more closely at the distal end of the radius while in males one should look at the 2nd and 3rd metacarpals.

Table 5 shows the intercorrelation between chronological age and overall skeletal age (TIM) with each of the bones and teeth. For the sexes combined, the highest correlations were obtained for the distal end of the radius (dr) and the upper cuspid (U3).

Table 6 and 7 show the intercorrelations between chronological age and overall skeletal age with each of the bones and teeth for the males and females, respectively. With the sexes segregated, the highest correlations were obtained for the proximal phalanx of the 3rd finger

Table 5

Rank-ordered (by CA) intercorrelations of chronologic and skeletal age with each bone and tooth (Sexes combined)

Ossific Center	Chronologic Age	Skeletal Age*
dr	.70	.80
pp4	.68	.74
pp3	.68	.74
M2	.67	.73
M3	.67	.73
pp2	.66	.73
pp5	.66	.73
mp4	.59	.71
Tooth		
U3	.78	.78
L4	.76	.77
L3	.75	.77
L7	.75	.76
U4	.74	.76
L5	.73	.76
U5	.73	.75
U7	.73	.71

*Skeletal age by Todd Inspection Method

(pp3) and the upper cuspid (U3) for the males, while for the females the strongest correlations were found with the distal end of the radius (dr), the upper cuspid (U3) and the lower cuspid (L3).

The correlation between overall skeletal age (TIM) and chronological age for the total sample was r=0.78. When the sexes were segregated, the almost identical value of r=0.77 was obtained for both males and females.

— Discussion —

Table 8 was created to facilitate comparison of previous studies with the results found in the present investigation, providing a brief description of the approach used and the findings of a number of investigations pertaining to the relationship between dental and skeletal maturation.

Examination of Table 8 reveals that most of the studies have attempted to compare overall skeletal age with the sequences and timing for dental eruption and calcification. As stated in the introduction, however, the timing and sequence of eruption have been found to be highly variable and influenced by a number of factors such as premature loss or prolonged retention of primary teeth, malpositioned teeth and ankylosed teeth.

Table 6

Rank-ordered (by CA) intercorrelations of chronologic and skeletal age with each bone and tooth (Males)

Ossific Center	Chronologic Age	Skeletal Age*
pp3	.71	.76
pp4	.69	.76
M2	.68	.74
M3	.68	.74
Dr	.66	.78
pp2	.66	.74
pp5	.65	.74
mp4	.58	.70
Tooth		
U3	.80	.80
L4	.77	.81
L7	.76	.81
L5	.76	.83
L3	.76	.80
U4	.75	.79
U5	.72	.78
U7	.70	.76

*Skeletal age by Todd Inspection Method

Table 7

Rank-ordered (by CA) intercorrelations of chronologic and skeletal age with each bone and tooth (Females)

Ossific Center	Chronologic Age	Skeletal Age*
Dr	.76	.84
pp4	.75	.79
pp2	.74	.79
pp5	.73	.77
pp3	.73	.78
M2	.72	.74
M3	.72	.74
mp4	.69	.80
Tooth		
U3	.77	.76
L3	.76	.74
U7	.75	.67
L7	.73	.68
L4	.74	.72
U4	.74	.73
U5	.74	.71
L5	.69	.68

*Skeletal age by Todd Inspection Method

Close comparison of the various studies is virtually impossible because of the many differences in methodology, the ages studied, and the sample sizes. These variables may also account for many of the differences in the conclusions offered in those studies.

It is curious that a number of studies and many clinicians traditionally use the adductor sesamoid of the thumb. However, the adductor sesamoid is characterized by great variability in the time of onset of calcification, and its appearance approximates the time when the teeth have already erupted into the oral cavity.

Although Chartkow and Fatti (1979) examined the relationship between the sesamoid bone and the calcification of the cuspids, the high correlation that they reported is misleading, since only one ossific center was used and the age range of 11-13yrs suggests prior apical closure of the cuspids. Thus, too little information about the calcification stages is provided.

The conflicting statements that have appeared in the literature regarding the nature and degree of relationship between human skeletal and dental maturation prompted this Author to address that issue by studying the relationship between specific teeth and the specific ossific centers characterized by a low degree of variability in the timing of their onset of ossification.

The findings in this investigation tend to conflict with the general notion that skeletal and dental maturation are relatively independent phenomena. The correlations found between calcification of the teeth (Dental Age, DA) and skeletal age as assessed by the eight ossific center method (OCM) were quite high, ranging from r=0.60 to r=0.82. Most of the correlations were slightly higher for the females (female $\overline{X}$r=0.76, male $\overline{X}$r=0.73) (Tables 3 and 4).

The data in Tables 2 through 4 indicate that the strongest correlations were obtained between the ossific centers and the lower cuspid, followed closely by the upper first bicuspid. These findings pertain to both sexes. In fact, the correlational sequence for the first five teeth is remarkably similar for the males and females (Table 3 and 4).

The second bicuspid seems least reliable in terms of the strength of its correlations with the ossific centers. This supports the the often-made statement that the most distal tooth in each tooth-type segment will be the most variable in morphology and in timing of maturation (lateral incisors, second bicuspids, and third molars) (Dahlberg 1945; Brown 1986).

The same subjects were used in assessing the nature and strength of the relationship between the calcification stage of each of the eight teeth (DA) and a single value for skeletal age as derived by the Todd Inspectional Method (TIM). The correlation values were quite high (ranging from r=0.62 to r=0.83), as was the case for the relationship between DA and OCM. However, a difference was observed in that the correlation values were consistently higher for the males when using TIM (male $\overline{X}$r=0.80, female $\overline{X}$=0.71), while the OCM produced higher values for the females (Tables 5-7).

Another difference between the two methods in relation to DA is that there are few similarities between males and females when the eight teeth are rank-ordered according to the strength of their relationship with the single skeletal age value provided by the TIM (Tables 6 and 7). Using the TIM, only the females showed a strong correlation with the cuspids.

As previously noted, the rank-ordering of the first five of the eight teeth was

Table 8

Previous Studies

Author	Year	Subject of Investigation	N	Age	Findings (r) Males	Both	Females
Woodrow & Lowell	1922	Hand-Wrist x-ray, overall	150	6.5	.20		.30
		Teeth present		9.5	.59		.24
		Males & females separated		11.5	.39		.30
		25/25					
Abernety	1925	Carpal development (H-W x-ray)	120	Var.			.31
		Permanent teeth erupted					
Perkins	1926	Dental eruption; Mental age; Chron. age ♂ ♀	556	Var.		.47	
Cattell	1928	Counting total number of teeth present	102	6.0	.45		.16
		Average age, anatomic indices; 55 ♂ 47 ♀					
				8.5	.31		.38
				10.5	.24		.14
		DA–CA (sexes combined)				.82	
Demisch & Wartmann	1956	Lower 3rd molars (stages); H-W x-ray (overall); sexes combined	120	9-16		.83	
		SA–CA				.79	
Lewis & Garn	1960	Lower 2nd & 3rd molars - pan and H-W x-ray (overall) (sexes comb.)	250	8-10		.30	
Steel	1964	Lateral mandbular x-ray, Lower 2nd bic. 2nd and 3rd molars	42	10-13	.15		.28
		H-W x-ray (overall) 21 ♂ 21 ♀					

Winshall	1967	Lat ceph (facial growth)	21	4.5-17			.94
		H-W x-rays (females)					
		Skel. - Chron. age					
Chartkow & Fatti	1979	U3, L3, 4, 5, 7 Tooth stages 1-8	140	11-13	.77		.77
		Pan x-ray, H-W x-ray					
		Presence of adductor sesamoid					
		No sex differece found					
Engstrom, Engstrom & Sagne	1983	Lower 3rd molars (pan x-ray) Stages 1-5	221	Var.			
		H-W x-ray pp2, mp4, dp3, dr					
		CA - DA			.85	.77	
		CA - SA (Sexes comb)				.88	
		DA - SA				.72	
Hagg & Taranger	1984	Tooth emergence 1-28	212	4-18		.30	
		H-W sesamoid & mp3					
		Better correlation with pubertal dev. (menarche & voice change),					
		Growth spurt peak and end					
Hagg & Matsson	1985	Upper left and lower right teeth erupted stages 1-3	300	3.5-6.5	.85		.69
				6.5-9.5	.32		.51
		Method of Gustafson & Koch		9.5-12.5	.45		.51
		Look at DA -CA 1974			.82		.82
		Method of Lilliequist & Lundberg			.47		.55
		Stages (1/7) Lower left 1971			.56		.54
		Method of Demirjian, stages 1-8, lower left 1973			.82		.82
					.48		.51
					.54		.51

virtually identical for males and females in relation to the OCM values, with strong correlation for both sexes. Only the rank-ordering of the ossific centers differed between the sexes.

Comparing TIM and OCM

A comparison of the two methods for evaluating skeletal age (OCM vs TIM) yielded high correlation values, with slightly higher values for females ($\bar{X}r = 0.78$ ♀, 0.74 ♂). The highest value for the TIM for both sexes was with the distal aspect of the radius. Beyond this, however, there were few similarities between the sexes. In fact, while mp4 showed the second-highest correlation with the TIM for females, it presented the weakest correlation of the eight for the males.

The relationships between chronological age (CA) and each of the two skeletal age assessment methods proved to be relatively strong. The TIM vs CA correlation value was 0.78 for the sexes combined, and 0.77 for both the males and the females taken separately. The OCM vs CA correlations were somewhat weaker, ranging from $r = 0.58$ to 0.71.

It is interesting to note that in the females, the distal epiphysis of the radius using the ossific center method (OCM) showed the highest correlations with DA, CA, and TIM.

The strong correlations between dental and skeletal maturation that are demonstrated in this investigation suggest that a radiographic determination of skeletal maturation is of lesser clinical importance in the treatment of children who fall within an essentially normal developmental range. This is particularly true if the clinician can determine the calcification status of the teeth (particularly L3) from a clear radiograph.

In atypical patients, such as those displaying Rickets, endocrinopathy, or cleidocranial dysostosis, or a local aberration such as fibromatosis gingivae, or any other sign of developmental disharmony, then the independent determination of the child's skeletal status can be a valuable adjunct.

It is the Author's impression that it is much easier and quicker to determine skeletal status by examining the maturational stages of specific ossific centers rather than by a subjective and general comparison of a hand-wrist radiograph using the Todd Inspectional Method. Fishman (1982) reaches a similar conclusion in presenting the Skeletal Maturation Assessment (SMA) method.

Although the correlations of DA with the TIM and the OCM are similar, use of the OCM provides essentially the same information from a quicker and easier assessment of skeletal age. This is particularly true if one selects the three or four teeth and ossification centers most highly correlated for the appropriate sex.

Although the rankings of the degree of variability in the time of onset of ossification for the eight centers are quite similar ($r = 0.88$) for the males and females, the ranking of the centers in terms of the strength of their relationship to the eight teeth is dramatically different ($r = 0.70$), with a strong inverse relationship. However, there is a distinct possibility that the maturational sequences may be quite different at the ages studied in this investigation.

It has been traditionally held that females mature at a more rapid rate than males throughout the growth period. The structure of the present study does not permit confirmation of this theory, since the 8-12yr age range was used for both sexes. It is likely that females are beginning to pass through puberty at this time, and that hormonal changes could differentially affect the ossific centers.

Because of the dramatic differences found between males and females in the rank-order of the correlations of the eight ossific centers with the eight teeth (Tables 3 and 4), one wonders whether comparison of a group of young males with a group of chronologically younger females would yield the same rank-order sequences as found in the present study.

This proved to be true. A comparison of the females from group 5 (9.5-10yrs) with the males from group 9 (11.5-12yrs) found the same sequences as when all 10 age groups were considered together. It appears that the degree of maturation (stages) of the ossific centers is greater for females than for the males in both age groups 5 and 9, and that the magnitude of difference (approximately one stage) is the same for both age groups.

It appears, then, that relating the least variable ossific centers to dental calcification stages results in relatively high correlations. This is most clearly evident in comparisons of the values found in this study with the results of other investigations (Table 8).

The Author is grateful for the helpful assistance of Drs. Melvin Baer (since deceased), Valmy Pangrazio, Richard Kulbersh, Richard Cole, Emet Schneiderman, Hector Ortiz, and Mrs. June Roberts.

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