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Interrelationships among measures of somatic, skeletal, dental, and sexual maturity

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The interrelationships among five measures of physiologic maturity for 50 French-Canadian girls are evaluated—(1) menarche, (2) peak height velocity (PHV), (3) 75% skeletal maturity, (4) appearance of the ulnar sesamoid, and (5) 90% dental development. The mean ages of occurrence of the events differed significantly ($P < 0.01$). Menarche and 90% dental maturity showed the least variability. Ages of PHV, menarche, and 75% skeletal maturity were significantly correlated ($P < 0.05$). Age of menarche was most closely associated with PHV. The appearance of the ulnar sesamoid was highly correlated with 75% skeletal maturity; both were equally related to the ages of PHV and menarche. The age at which French-Canadian girls attain 90% of their dental development showed no significant relationships with the other maturity indicators. The results imply that the mechanisms controlling dental development are independent of somatic and/or sexual maturity. (AM J ORTHOD **88:** 433-438, 1985.)

Key words: Physiologic maturity, French-Canadian, growth

Human growth shows considerable variation in the chronologic ages at which individual children reach similar developmental events. As such, the developmental status of a child is best estimated relative to specific stages of physiologic maturity. In practice, we may distinguish among four physiologic or developmental indices: somatic, skeletal, dental, and sexual maturity. Theoretically, strong relationships among indices imply a concordance of controlling mechanisms, which serve clinicians in diagnosis and treatment planning. Valid associations also provide a means of prediction, allowing judgments to be based on a single examination. This is particularly important during adolescence when changes in growth rate can influence treatment results. On the other hand, the lack of association among maturity indices implies an additional, independent tool for the evaluation of biologic systems.

It is presently agreed that some general factor of body maturity exists that results in a tendency for a person to be advanced or delayed as a whole.[1] Skeletal maturity, perhaps the most commonly used index in routine clinical work, is closely related to sexual and somatic maturity. Girls who are skeletally advanced also menstruate early.[2-5] Simmons and Greulich[6] demonstrated this relationship and confirmed that age of menarche is more closely related to skeletal maturity than chronologic age. Since skeletal maturity and the appearance of the ulnar sesamoid are related,[7] correlations between the appearance of the ulnar sesamoid and menarche are also consistently high.[2,4,7-10] Other investigations have confirmed that peak height velocity (PHV) is closely related to both skeletal age[5,11,12] and the appearance of the ulnar sesamoid.[7,9,12-15] A strong relationship also exists between menarche and PHV.[9,12,16-20] Deming[21] reported the highest relationship ($r = 0.93$) between menarche and age of peak height velocity as derived from individually fitted growth curves.

Although the interrelationships of somatic, skeletal, and sexual maturities are consistent, their associations to dental maturity are relatively low or insignificant. The highest correlations pertain to dental emergence and age of menarche. Nanda,[22] using age at completion of the permanent dentition, and Lewis and Garn,[23] using age of attainment of the occlusal level of the second molars, obtained correlations approximating 0.60. Shuttleworth[16] reported that girls with an early PHV are more advanced in dental emergence. Engström, Engström, and Sagne[24] found a strong positive correlation between skeletal and third-molar development. Others have reported lower correlations betwen skeletal and dental development, and conclude that the developmental systems are independent of one another.[25-31,41] The inconsistency of results is caused by different methods and approaches in data collection. For example, some investigations use single stages of

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Table I. Statistics describing the attainment of physiologic maturity indices for French-Canadian girls

Maturity index	N	Mean	SD	CV (%)	Min.	Max.
90% dental development	49	9.99	0.68	6.83	8.20	11.70
75% skeletal development	50	10.39	0.81	7.80	8.30	12.10
Appearance of ulnar sesamoid	48	10.98	0.99	9.01	8.50	13.50
Peak height velocity	46	11.97	1.11	9.25	9.75	15.00
Menarche	47	12.91	0.82	6.21	10.70	14.10

SD = Standard deviation.
CV = Coefficient of variation.

dental development, while others employ different ways to analyze the results (that is, use of specific ages or all ages combined).

To further examine these developmental interrelationships, this investigation evaluated the skeletal, somatic, sexual, and dental maturity of French-Canadian girls. The resulting descriptions provide reference data currently unavailable. In contrast to the majority of previous investigations, which have focused on the relationships of two, or perhaps three, developmental indices, we propose to examine all four simultaneously.

MATERIAL AND METHODS

Data were derived from the work of the Montreal Human Growth Research Centre. They pertain to a cohort of 50 girls between 6 and 15 years of age, who were followed longitudinally from 1967 to 1976. The children visited the Centre annually. Over 90% of the visits were within 15 days of the child's birthday; examinations made more than 30 days from the birth date were excluded from the analysis.

The sample is representative of the French-Canadian population of Montreal. Sampling was confined to children with at least three French-Canadian grandparents. The subjects attended three school districts that represented different socioeconomic sections of Montreal. Although the sample is somewhat biased in terms of the children who remained with the study (as is always the case in longitudinal work), the socioeconomic status of the parents at the beginning and toward the end of the project compares with the Montreal population as a whole.

For each child five indices of physiologic maturity were recorded for evaluation: menarche, peak height velocity (PHV), appearance of the ulnar sesamoid, skeletal development, and dental development. Age of menarche was obtained prospectively. At each visit the girls were asked if they had begun to menstruate. If the reply was positive, the exact age at the date of menarche was recorded. Age of PHV was estimated graphically from each girl's longitudinal series by means of rules predicated upon the relative positions of the three points adjacent to the peak velocity. Reproducible estimates of PHV were made to within the nearest 3 months. The age of appearance of the ulnar sesamoid was estimated from hand-wrist films as the midpoint between the first film showing the sesamoid and the previous film.

Because of the large number of possible stages available for skeletal and dental maturity, only one index value was derived for each stage. For the purposes of this analysis, 75% skeletal maturity and 90% dental development were chosen as the index ages upon which to make comparisons. For predictive purposes, we sought indices that reflected growth status close, but prior, to the ages of the other three maturity indices (that is, age of menarche, PHV, and the appearance of the ulnar sesamoid). Skeletal maturity was calculated according to the full, 20-bone TWII weighting system,[30] coded from left hand-wrist films. Chronologic age at 75% skeletal maturity was estimated from each girl's longitudinal maturity records. Skeletal maturity was plotted relative to chronologic age; the curves were smoothed by hand and the age at 75% skeletal maturity was interpolated. Dental maturity was obtained from panoramic radiographs following the tooth rating system of Demirjian, Goldstein, and Tanner.[33,34] The exact age corresponding to 90% dental maturity was estimated from plots of each girl's longitudinal data following the procedures previously described for skeletal maturity.

RESULTS

Table I gives descriptive statistics for the ages of occurrence for the five indices. Ninety percent dental maturity occurred at the youngest mean age—9.99 years. This was followed by 75% skeletal maturity at 10.39 years, the appearance of the ulnar sesamoid at 10.98 years, PHV at 11.97 years, and menarche at 12.91 years. The age distributions for each of the indices were normal; skewness and kurtosis showed no significant departures from normality ($P < 0.05$). Relative variability of the measures as described by the coefficients of variation ranged from 6.21% to 9.25%. PHV was the most variable index followed closely by

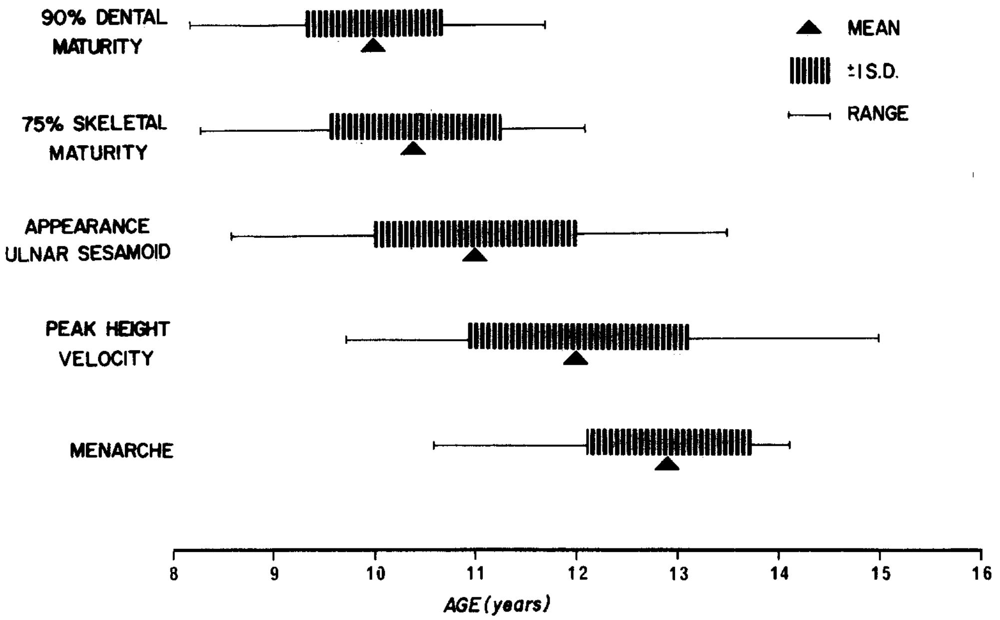

Fig. 1. Descriptive statistics for the attainment of five maturity indices by French-Canadian girls.

Table II. Intercorrelations of dental, somatic, skeletal, and sexual maturity for French-Canadian girls

Maturity index	*Skeletal development*	*Ulnar sesamoid*	*Peak height velocity*	*Menarche*
90% dental development	0.17	−0.03	−0.16	−0.10
75% skeletal development	—	0.86***	0.41**	0.40**
Appearance of ulnar sesamoid	—	—	0.57***	0.44**
Peak height velocity	—	—	—	0.81***
Menarche	—	—	—	—

** = $P < 0.01$.
*** = $P < 0.001$.

the appearance of the ulnar sesamoid. Menarche and 90% dental maturity were the least variable indices. Assuming similar patterns of relative variability at other stages of dental maturity, the results suggest that tooth formation provides one of the best indicators of chronologic age when the latter is unknown.

Fig. 1 graphically compares the mean ages of occurrence plus or minus one standard deviation and the ranges of variation for the five maturity indicators. The ulnar sesamoid appeared and menarche occurred approximately 1 year before and after PHV. Age of menarche compared to the mean age of menarche (13.08 years) previously reported for a cross-sectional sample of 1,002 French Canadian girls.[35] Seventy-five percent skeletal maturity occurred approximately 1½ years before PHV; 90% dental development occurred approximately 2 years before PHV. Student t tests comparing the differences of means for the ten pairs of indices were all significant ($P < 0.01$).

Pearson's product-moment correlations for the five indices are reported in Table II. Skeletal maturity (including 75% skeletal maturity and the appearance of the ulnar sesamoid), somatic maturity, and sexual maturity all showed significant positive associations ($P < 0.001$). The appearance of the ulnar sesamoid and 75% skeletal maturity, the two indices pertaining to osseous development, showed the highest correlations. Age of menarche and PHV also demonstrated strong associations. The remaining relationships were moderately low, ranging from 0.40 to 0.57. This is partly attributable to the differences in the ages at which these events occurred. If, for example, we had chosen a skeletal event coinciding more closely with PHV, stronger associations might be expected. Dental maturity showed no significant relationships with the four other maturity indices.

DISCUSSION

The results compare favorably with previously published reports in terms of both their relative timing and interrelationships. Our finding that PHV precedes menarche by approximately 1 year is consistent with the

Table III. Intercorrelations of physiologic maturity for females

Source	Sample size	Correlation
PHV and skeletal age		
Marshall ('74)	33	0.74
Houston ('80)		
RUS at 11 years	49	−0.71
RUS at 12 years	51	−0.73
RUS at 13 years	48	−0.71
Ekström ('82), TW2 at 12 years	23	−0.63
Present study	46	0.41
PHV and appearance of ulnar sesamoid		
Björk and Helm ('67)	20	0.57
Brown, Barrett, and Grave ('71)	14	0.85
Grave and Brown ('76)	17	0.85
Onat and Numan-Cebeci ('76)	64	0.67
Hagg and Taranger ('80b)	78	0.63
Ekström ('82)	22	0.53
Present study	46	0.57
PHV and menarche		
Shuttleworth ('39)	246	0.71
Nicolson and Hanley ('53)	65-82	0.71
Deming ('57)	24	0.93
Björk and Helm ('67)	20	0.49
Marshall and Tanner ('68)	45-97	0.91
Filippson and Hall ('76)	83	0.63
Haff and Taranger ('80a)	79	0.77
Ekström ('82)	47	0.73
Present study	46	0.81
PHV and dental development		
Meredith ('59)		
Canine eruption	43	0.31
1st molar eruption	43	0.19
2nd molar eruption	43	0.20
Nanda ('60), Permanent teeth eruption	34	0.38
Grøn ('62)	440	No relation
Björk and Helm ('67)		
Dental eruption, stage 4	20	0.42
Dental eruption, stage M2	20	0.37
Filippson and Hall ('76)		
1st molar eruption	83	0.20
Hägg ('80)		
Canine and premolar emergence	79	0.27
2nd molar emergence	79	0.23
Ekström ('82)		
Canine and premolar eruption	50	0.22
Canine and 2nd molar eruption	50	0.03
2nd molar eruption	50	−0.15
Dental stage at 12 years	24	0.03
Present study	46	−0.16
Ulnar sesamoid and menarche		
Flory ('36)	—	0.75
Buehl and Pyle ('42)	30	0.71
Garn and Rohmann ('62)	81	0.65
Björk and Helm ('67)	20	0.66
Frisancho, Garn, and Rohmann ('69)	110	0.70
Present study	47	0.44
Skeletal age and menarche		
Flory ('36)		
Age 11	—	−0.68
Skeletal age and menarche—Cont'd		
Age 13	—	−0.85
Shuttleworth ('37)	—	−0.71
Buehl and Pyle ('42)	30	0.74
Simmons and Greulich ('43)		
Age 10	124	−0.59
Age 11	159	−0.68
Marshall ('74)	59	0.35
Present study	47	0.40
Dental development and menarche		
Lewis and Garn ('60)		
2nd molar eruption	35	0.61
Nanda ('60), Permanent teeth eruption	34	0.59
Garn, Lewis, and Kerewsky		
Crown completion PM2	55	0.15
Apical closure M1	30	0.17
Crown completion M2	63	0.34
Begin calcification M3	64	0.07
Björk and Helm ('67)		
Dental eruption, stage 4	20	0.19
Dental eruption, stage M2	20	0.20
Present study	47	−0.10
Ulnar sesamoid and skeletal age		
Onat and Numan-Cebeci ('76)	75	0.51
Present study	48	0.86
Ulnar sesamoid and dental development		
Björk and Helm ('67)		
Dental eruption, stage 4	20	0.35
Dental eruption, stage M2	20	0.29
Present study	48	−0.03
Dental development and skeletal development		
Cattell ('28)		
Teeth eruption at age 6	—	0.16
Teeth eruption at age 8.5	—	0.38
Teeth eruption at age 10.5	—	0.14
Garn, Lewis, and Kerewsky ('65), at skeletal age 15 years		
Crown completion PM2	37	−0.25
Apical closure M1	18	−0.02
Crown completion M2	46	−0.34
Begin calcification M3	39	−0.25
Steel ('65)		
2nd premolar at age 12	21	0.13
2nd molar at age 12	21	0.37
3rd molar at age 12	19	0.01
Average at age 12	21	0.28
Anderson, Thompson, and Popovich ('75)		
3rd molar stage, average of ages 4-14 years	111	0.18
Patterson and associates ('84)		
3rd molar stage, average of ages 7-16 years	35-109	0.08
Present study	49	0.17

literature.[1,28] Björk and Helm[9] also reported a difference of 1 year between the appearance of the ulnar sesamoid and PHV; Chapman[36] showed a difference of 9.4 months from longitudinal radiographs taken at 3-month intervals.

The interrelationships obtained for French-Canadian girls are compared with previous studies in Table III. Our results are somewhat lower because of (1) differences in the mean ages of the events associated and (2) the use of a maturity scale that included the majority of the dental components, rather than isolated teeth or events. For example, the maturity of the canines appeared to be more closely associated with PHV than the other teeth.[12,37,38] The higher correlations between 75% skeletal maturity and the appearance of the ulnar sesamoid might be related to the methods employed. Onat and Numan-Cebeci[7] obtained a correlation of 0.51 using skeletal age at the appearance of the ulnar sesamoid. The remaining relationships compared favorably with those previously reported.

All the developmental indices—skeletal, height, sexual, and dental—progressed in parallel during the growth period; they followed the same chronologic path. Lamons and Gray[39] compared their progression to

> a company of soldiers who are moving at a constant rate of speed. Now one pair walks together, then they divide and walk with others. Some run ahead, others lag behind and even stop to rest; yet all reach the same goal in the forward advance of events.

To take full advantage of the soldiers' potential, information about their specific roles and degrees of interrelationship is required. Thus, we establish population-specific standards and evaluate the relationships among indices.

There remains little doubt that PHV, skeletal development, and sexual maturation are closely associated. Skeletal and somatic maturity belong to the same system; they pertain to mesodermal tissues regulated by pituitary and gonadal secretions, which influence ossification of the epiphyseal cartilage and result in growth of long bones. Biologically, the associations suggest a common mechanism that adjusts the output of pituitary hormones; these, in turn, activate the adrenal cortices and ovaries during puberty.

The picture is less clear for dental development. Its low associations with skeletal, somatic, and sexual maturity may be attributed to differences in scale (that is, the dental scale may be more or less precise than the other scales) or to the independence of controlling mechanisms. Clearly, the same attributes are not being measured. The latter interpretation is supported by the ectomesenchymal derivation of the dentition. Demirjian[40] provides a detailed discussion of these issues as they relate to the deciduous dentition.

In conclusion, the results substantiate that skeletal, somatic, and sexual maturity are interrelated presumably by a common controlling mechanism. These associations allow clinicians to better assess a person's developmental status and make future predictions (that is, the timing of ulnar sesamoid ossification appears to be a good predictor of PHV). Dental development is unrelated to the other developmental systems. It is subject to less variation in relation to chronologic age and appears to be controlled independently. As such, temporary disharmonies between dental and somatic/skeletal development might be anticipated.

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