

Prediction of the Age of Maximum Puberal Growth in Body Height

A. BJÖRK, D.D.S., Odont. Dr.

S. HELM, D.D.S.

Copenhagen, Denmark

The age at the onset of puberty varies with sex, generation, population and environment, and differs greatly from one person to another. An understanding of the relationship between the age at maximum puberal skeletal growth and other criteria of physical maturation can be of value in several respects in connection with the care of the growing child, for instance, when it is desired to know whether or not the puberal growth spurt for an individual has been reached or passed. The present analysis of longitudinally collected data relating to Danish children is limited to this specific problem: the age at maximum puberal growth in body height is judged in relation to other stages of skeletal maturation, mineralization of one of the sesamoid bones of the thumb, two selected stages of dental development, and, in girls, the menarche. The reason for including the sesamoids of the metacarpophalangeal joint of the thumb is that they are the only consistent ossification centers in the hand that appear near puberty.

METHOD

The data for the study relate to Danish children of both sexes in sound clinical health; they belong to a longitudinal study of facial growth being conducted since 1951 at the orthodon-

tic department of the Royal Dental College, Copenhagen, with the special purpose of examining the growth of the face by a radiologic technique involving metallic implants.^{2,3} The children were enrolled without regard to birthday and have been examined annually. Because of the special nature of the growth study the number of children enrolled was limited and the incidence of malocclusion in the samples is greater than in the general population. For the present analysis thirty-two boys and twenty girls were selected in whom all stages of physical maturation examined had been reached and determined. Approximately half of the children had had some form of orthodontic treatment.

The ages at which the stages of physical maturation were recorded were defined as follows:

Maximum puberal growth in body height (H): The age was recorded midway through the annual period during which puberal growth, calculated from individual growth curves, was greatest. The registration was selected as representative of the growth of the skeleton.

Ossification of the ulnar sesamoid at the metacarpophalangeal joint of the thumb (S): The age at onset of ossification of the ulnar sesamoid at the metacarpophalangeal joint of the thumb was taken as six months before the examination at which ossification was first evident in radiographs of the right hand. The radiographs were taken in an x-ray cephalostat with a focus - film

This investigation was supported by a U.S.P.H.S. research grant HD - 154 from the National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, Maryland, U.S.A., and by grants from the Danish State Research Foundation.

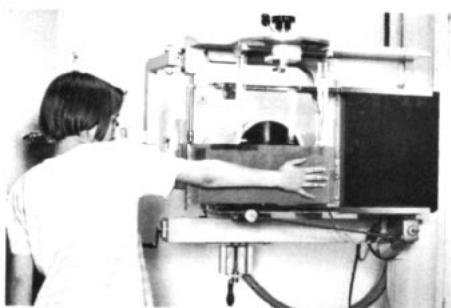


Fig. 1 Radiographing the right hand in the cephalostat.

distance of 190 cm on non-screen film; no grid; 60 kV (Fig. 1). The ulnar sesamoid (Fig. 2) is related to the adductor pollicis muscle. The radial sesamoid is related to the flexor pollicis brevis muscle and on the radiographs is usually overshadowed by the first metacarpal, so that it is not always visualized; it was therefore not included in this study.

Menarche (M): The age at menarche was recorded as the midpoint of the chronological year of age during which it occurred.

Dental stages. DS 4: All canines and premolars fully erupted.

DS M_2 : All second molars fully erupted.

These are two well-defined stages in dental maturation around puberty. The classification is taken from that introduced by Björk, Krebs and Solow.⁴ The teeth are considered to be fully erupted when they have reached the occlusal level, and the age at attainment of these dental stages was taken to be six months before the examination when the criterion of the dental stage was first fulfilled. This observation was made on dental casts. Cases were excluded in which a dental stage could not be determined because of aplasia, or extraction of more than one canine, premolar or first molar.



Fig. 2 Radiograph of the hand showing the ulnar sesamoid of the metacarpophalangeal joint (arrow).

FINDINGS

The mean chronological ages at which the various stages of physical maturation occurred are given in Table I, with the relevant distribution parameters.

Certain departures from normality were expected. However, for none of the stages did the distribution differ significantly from normality, as judged by tests of skewness and kurtosis.

The sex differences in chronological age for the various stages of maturation can be calculated from Table I. The maximum puberal growth in body height occurred 18 ± 3.0 months earlier in girls than in boys, and ossification of the ulnar sesamoid of the thumb 21 ± 3.0 months earlier in girls. The sex difference in dentitional development was considerably smaller, full eruption

TABLE I
MATURATION STAGES IN YEARS AND MONTHS

	Mean	Error of the Mean	Standard Deviation	Range
<i>32 Boys</i>				
Max. height (H)	14-0	0-1.93	0-10.93	12-5 to 15-10
Sesamoid (S)	13-3	0-1.99	0-11.23	11-0 to 15-6
DS 4	12-11	0-3.10	1-5.54	10-7 to 16-6
DS M ₂	14-1	0-2.79	1-3.78	11-1 to 17-4
<i>20 Girls</i>				
Max. height (H)	12-6	0-2.27	0-10.13	11-2 to 14-4
Sesamoid (S)	11-6	0-2.31	0-10.32	10-2 to 13-4
DS 4	12-9	0-4.14	1-6.51	10-10 to 16-4
DS M ₂	13-7	0-3.80	1-5.00	11-0 to 16-4
Menarche (M)	13-11	0-2.68	0-11.98	11-6 to 15-6

to the occlusal level of all the canines and premolars (DS 4) being attained only 2 ± 5.2 months earlier in girls, while full eruption of all the second molars (DS M₂) was earlier in girls by 6 ± 4.7 months. The sex differences were thus considerably greater for maximum puberal growth and for ossification of the sesamoid than for dental development.

These two groups of maturation stages differed also as regards the ranges (Table I). The ages at maximum puberal growth, ossification of the sesamoid, and menarche showed ranges of variation of 3-4 years, while those for the two dental stages were nearly twice this, or 5-6 years. This shows that the dental development was less strongly associated with chronologic age than the growth maximum, ossification and menarche. For all the stages of maturation the sex differences in the ranges were small and insignificant.

The possibilities of predicting puberty can be judged both from the mean ages at the different stages of maturation (Table I) and from individual associations between these ages (Table II). In this table the ages at the other

stages of maturation are given, distributed with respect to the years by which they preceded or succeeded the year for the maximum puberal growth in body height.

The sesamoid was ossified on an average 12 ± 2.1 months before maximum puberal growth for the girls and 9 ± 1.4 months before for the boys (Table I). Individually, the ossification either preceded or coincided with maximum puberal growth, and this relation was the same for both sexes (Table II). Onset of ossification of the sesamoids therefore indicated that maximum puberal skeletal growth was imminent or attained.

The menarche occurred on an average 17 ± 2.5 months after maximum puberal growth; in some it fell in the same year and in others later (Table II). The menarche was therefore an indication that maximum puberal skeletal growth was attained or had been passed.

The relation of the development of the dentition to the maximum puberal growth displayed a marked sex difference (Table I). In the boys full eruption of all the canines and premolars (DS 4) was complete about one year

TABLE II

Distribution of age at ossification of the sesamoid (S), at two dental stages (DS 4 and DS M₂) and at menarche (M), in relation to the year for maximum puberal growth in body height (H).

Years	—4	—3	—2	—1	Max. Height (H)	+1	+2	+3	+4
32 Boys									
S			4	17	11				
DS 4	1	6	6	7	7	5			
DS M ₂		2	3	5	11	6	3	2	
20 Girls									
S		1	3	11	5				
DS 4			1	5	7	5	—	1	1
DS M ₂				3	3	8	3	2	1
M					5	6	4	5	

(13 ± 3.1 months) before maximum puberal growth, while for the girls it occurred at about the same time (3 ± 3.8 months after). Full eruption of all the second molars (DS M₂) in the boys coincided with maximum growth (1 ± 3.2 months after), while for the girls it was found to occur one year (13 ± 3.6 months) after.

The ranges for the dental stages in relation to the age at the maximum puberal growth (Table II) were large (6-7 years) compared with those for the ossification of the sesamoid and the menarche (3-4 years). Moreover, as maximum puberal growth fell within the ranges for the dental stages, these are unsuitable as indicators of the age at maximum skeletal growth. However, for most of the boys DS 4 preceded maximum skeletal growth, and for most

of the girls DS M₂ succeeded it, so that these stages will provide an indication of whether or not puberty has been attained, although a less reliable one than the sesamoid and the menarche.

In order to study further the association between the ages at the various stages of maturation a correlation analysis was performed (Table III) after a check of the form of the two-dimensional distributions. These were tested for departure from normality by Solow's method,³¹ and no significant departures were found.

The correlation coefficients fell into three, fairly well-defined groups, which were similar for the two sexes (Table III): (1) The ages at maximum puberal skeletal growth, ossification of the sesamoid and menarche were cor-

TABLE III
INTERCORRELATIONS OF MATURATION STAGES

H/S	H/M	S/M	DS 4/DS M ₂	DS 4/H	DS 4/S	DS 4/M	DS M ₂ /H	DS M ₂ /S	DS M ₂ /M
32 Boys									
r ¹⁾	.75	—	.65	.32	.31	—	.11	.10	—
20 Girls									
r ¹⁾	.57	.49	.66	.42	.35	.19	.37	.29	.20

H, age at puberal maximum in body height; S, age at ossification of the sesamoid; M, Menarche; DS 4 and DS M₂, age at occurrence of dental stages.

1) The .05, .01 and .001 significance levels are for boys: r=.35, r=.45, and r=.56, and for girls: r=.45, r=.57, and r=.68.

related with coefficients of between .49 and .75. (2) The ages at the occurrence of the dental stages DS 4 and DS M₂ showed correlation coefficients of .65 and .87. (3) The correlation between the ages in the two groups showed consistently lower values, .10 to .42. The analysis thus established the presence of two systems of development—a general physical and a specific dental one.

There was no definite sex-linked dissimilarity in the strength of the association between the various stages of maturation. The association of age at eruption of the second molars with age at maximum puberal growth and age at ossification of the sesamoid was considerably weaker in boys (.11 and .10) than in girls (.37 and .29), but the samples were too small to establish whether this difference was real or due to sampling errors.

DISCUSSION

Child development depends upon individual variations in the magnitude of growth and in the time required to reach maturity. A characteristic of the maturation process, apart from the fact that it differs according to sex, is that the age for the puberal growth spurt is approximately the same for the various parts of the body and organs, whereas the age when maturity is reached is greatly differentiated.^{3,34} The difficulty of establishing the stages of maturation lies in the fact that there is no exact grading, this being indicated only indirectly. Stages of maturation can be determined, or at least estimated, in several ways.

One way is to calculate the mean age for the appearance of each of the various centers of ossification or for epiphyseal closure, and the variations in these ages.^{1,12,28,30,35} In the hand such stages are present in the first part and at the end of the maturation scale, but at puberty the only centers which ossify

consistently are the metacarpophalangeal sesamoids of the thumb.

In girls the menarche likewise provides a stage of maturation recordable around puberty.

For the dentition, stages for evaluation of maturation are provided by tooth formation¹⁶ or eruption.⁴

As the magnitude of growth shows periodical fluctuations, evaluation of stages of maturation can also be based upon the ages at which the characteristic changes in the rate of growth occur (Fig. 3). Means and ranges of variation for the ages at the occurrence of such stages have therefore been calculated.³

The association between the maturation scale based on stages of ossification and that based on stages of growth rate has not yet been completely analysed. The present study is limited to an analysis of this association at puberty and to the possibility of predicting this time. As is evident from the results, the association between ages at ossification, menarche and maximum rate of growth is close, while these criteria are only

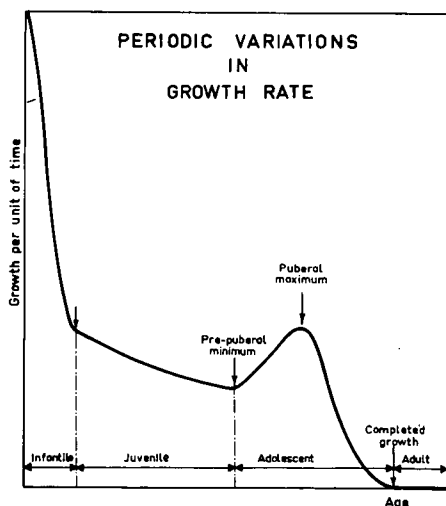


Fig. 3 Stages of skeletal maturation defined by ages at periodic changes in rate of growth.

weakly associated with the stages of dental development.

In the present study little emphasis is placed on means and forms of distribution for the ages at which the stages of maturation occurred, because the samples are small and different registration methods complicate comparison with the findings of other workers. For the Danish population comparable data are available only for the age at the menarche.⁵

For skeletal growth, the sex difference in the mean age at maximum puberal growth in body height was 18 ± 3.0 months, which is somewhat less than that usually reported.^{9, 29, 33}

The only stage of ossification analysed in this study was the age at ossification of the ulnar sesamoid at the metacarpophalangeal joint of the thumb. The two sesamoids at this joint are said to appear in nearly all persons,^{19, 20} and thus not to display the inconsistency typical of the other sesamoids of the hand. A scrutiny of the hand radiographs for all the subjects enrolled for the implant study disclosed one example of absent ossification of the ulnar sesamoid in each sex. For a precise determination of the incidence of this inconsistency, however, a larger sample is required. The sex difference in ossification age for the sesamoid was 21 months which is close to that for maximum puberal growth. A similar or somewhat greater sex difference is given in the literature.^{11, 15, 29, 30} Flory¹¹ and, later, Buehl & Pyle⁶ analysed the association between age at ossification of the ulnar metacarpophalangeal sesamoid and menarche and gave correlation coefficients of .75 and .71, respectively. Garn & Rohmann¹⁵ found a coefficient of .65 which is close to that in the present study (Table III). The last mentioned authors report a lower correlation of the ossification of the sesamoid with

the ossification of the round bones and epiphyses of the hand than with the closure of the epiphyses of the long bones. They stress the importance of the sesamoid as an indicator of maturation. A close association between age at ossification of the sesamoid and age at maximum puberal growth in body height has been mentioned in the literature, but no correlation coefficients seem to have been given. In the present sample high correlation coefficients were found (Table III). In more than half of the sample ossification of the ulnar sesamoid of the thumb occurred one year before maximum puberal growth (both sexes); it never occurred after this maximum (Table II). Thus, this stage of ossification seems to indicate fairly reliably that maximum puberal skeletal growth is imminent or has been reached.

The mean age of 13 years and 11 months for the menarche is close to that obtained in a representative cross-sectional study in 1950 in Copenhagen (13 years and 9 months).⁵ In that study a standard deviation of one year was calculated, but there were occasional cases with the menarche as early as 10 years and as late as 21, the distribution thus displaying positive skewness. The range was smaller for the present sample, which does not include extreme cases. For other populations the reader is referred to Tanner's comprehensive review of the literature.³⁴ The relation of the age at the menarche to the age at maximum puberal growth in body height is well documented.^{9, 18, 32} In the present series the menarche was recorded on an average 17 months after maximum puberal growth. Since it never occurred earlier than maximum puberal growth (Table II), the menarche is a reliable indication that the puberal growth spurt has been reached or passed.

The dental development was judged

on the basis of two dental stages (DS 4 and DS M₂), each consisting in the eruption to the occlusal level of all the teeth of a given group. Although the dental development can be determined more accurately on the basis of the formation or emergence of the individual tooth, the group system has the advantages that the registration is simple and that only a small number of well-defined stages is involved; the registration is therefore convenient not only for clinical use, but also for comprehensive epidemiologic studies. It has been suggested that the age of eruption is more dependent on environmental factors, such as loss of teeth and crowding, than is tooth formation.^{17,24} The effect of loss of teeth was eliminated to some extent by choosing criteria of dental development based on the eruption of groups of teeth instead of individual teeth, but the influence of premature loss of deciduous molars could not be assessed,¹⁰ nor could the effect of crowding or orthodontic treatment. The ages for the dental stages (DS 4 and DS M₂) are not directly comparable with those for the eruption of the individual teeth, which are usually given as the mean age for the emergence through the gum of homologous teeth of each jaw.^{7,8} The small sex difference in age at occurrence of DS M₂ (6 months) is consistent with the value usually given for the sex difference in age at formation and emergence of the second molars in each jaw.^{7,8,13,14,17} The mean age at DS M₂ in particular may have been slightly higher in the present samples than in the population.

That the sex difference is smaller for dental development than for "skeletal age", expressed as the degree of ossification, has been shown in many studies, and particularly clearly by Garn *et al.*¹³ The correlation between the age at eruption of the second molars

and the age at maximum puberal growth in body height has been reported,²² as has the correlation between the age at eruption of this tooth and the age at the menarche. As illustrated in Fig. 4, the sex difference in the intervals between occurrence of the dental stages (DS 4 and DS M₂) and maximum puberal growth was greater (16 and 12 months, respectively) than were the sex differences in chronologic age at occurrence of the dental stages (2 and 6 months). Neither of the dental stages was, however, of much value in predicting puberty, since the ranges included the puberal growth spurt, but DS 4 in boys and DS M₂ in girls provide some guide in this respect. On the basis of data from the literature^{7,22,27} Tanner³⁴ has found the eruption of some of the teeth more closely related to puberty in girls than in boys. The higher correlation between DS M₂ and other criteria of puberty in girls than in boys in the present samples (Table III) bears out this view, but confirmation in larger samples is needed.

It has been shown clearly by Moorrees *et al.*^{23,25} that the dental arch dimensions and the space conditions during development are considerably more strongly associated with dental age than with chronologic age. On the other hand, it is established that around puberty growth of the face and jaws closely follows the same maturation scale as general skeletal growth, represented by body height.^{3,26}

It may therefore be of practical importance in clinical orthodontics to be able to assess the development of the various systems of maturation. Since growth in body height is the dimension by which maximum puberal skeletal growth is most easily determined, measurement of the annual growth in body height is recommended as a routine procedure in orthodontic cases treated over a long period. Where such

MATURATION STAGES AT PUBERTY

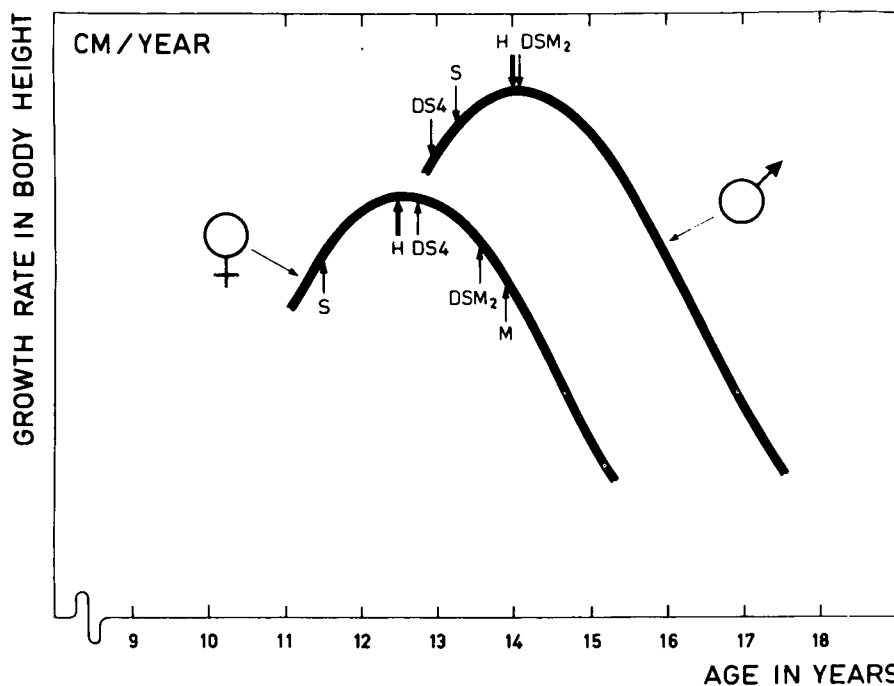


Fig. 4 Sex differences in mean ages at physical stages of maturation at puberty, marked off on the growth curves for the two sexes. H, maximum puberal growth in body height; S, ossification of the sesamoid; M, menarche; DS 4 and DS M₂, dental stages.

longitudinal data are not available, radiologic examination of the ossification of the ulnar sesamoid of the thumb may provide a guide with the reservation that, in single cases, ossification may possibly not occur. This indicator of maturation has two advantages: its observation does not depend on a longitudinal technique, it is easily recorded on a dental film. In girls, routine registration of the menarche may be of great value. Dental maturity in the years around puberty may be judged with the simplified criteria DS 4 and DS M₂.

It should be pointed out that while maximum puberal growth occurs at approximately the same time for the upper face, the mandible and body height, growth ceases at different ages,

and this complicates the prediction of residual growth.³

SUMMARY

The possibility of predicting the age at maximum puberal growth in body height from other criteria of maturation has been evaluated on a longitudinal basis. The study was performed on twenty girls and thirty-two boys, all Danish.

There was a close association between the age at maximum growth in body height and the age when ossification of the ulnar metacarpophalangeal sesamoid of the thumb occurred, and also in girls, the age at the menarche. The sesamoid did not ossify after maximum puberal skeletal growth, and it usually ossified one year before; conversely,

the menarche did not occur before this age, and it was recorded up to a few years later. The dental development, on the other hand, was of little value as a criterion of puberty, since the eruption to the occlusal level of all the canines and premolars (DS 4), especially for the girls, and eruption to the occlusal level of all the second molars (DS M₂), especially for the boys, could occur several years before or after maximum puberal skeletal growth.

It was concluded that in clinical orthodontics both skeletal and dental maturation should be registered. Important criteria of maturation at puberty are: the age at maximum puberal growth in body height, the age at ossification of the ulnar sesamoid of the thumb, and, in girls, the age at the menarche. Criteria of dental maturation around puberty that display a weaker association are two dental stages, DS 4 and DS M₂.

Royal Dental College

REFERENCES

1. Acheson, R. M. The Oxford method of assessing skeletal maturity, *Clin. Orthop.*, 10: 19-39, 1957.
2. Björk, A. Variations in the growth pattern of the human mandible: Longitudinal radiographic study by the implant method, *J. Dent. Res.*, 42: 400-11, 1963.
3. Björk, A. Sutural growth of the upper face studied by the implant method, *Europ. orthodont. Soc. Trans.*, pp. 49-65, 1964, and *Acta odont. scand.*, 24: 109-27, 1966.
4. Björk, A., Krebs, Aa, and Solow, B. A method for epidemiological registration of malocclusion, *Acta odont. scand.*, 22: 27-41, 1964.
5. Bojlen, K., Rasch, G., and Weis Bentzon, M. The age incidence of the menarche in Copenhagen, *Acta obstet. gynec. scand.*, 33: 405-33, 1954.
6. Buehl, C., and Pyle, I. The use of age at first appearance of three ossification centers in determining the skeletal status of children, *J. Pediat.*, 21: 335-42, 1942.
7. Clements, E., Davies-Thomas, E., and Pickett, K. Time of eruption of permanent teeth in British children in 1947-8, *Brit. med. J.*, 1: 1421-4, 1953.
8. Degerbøl, M. Om tandskiftets forløb hos Københavnske kommuneskolebørn. Med henblik på tandskiftet hos de øvrige primater, *Medd. Danmarks Antropologi*, III: 237-327, 1931.
9. Deming, J. Application of the Gompertz curve to the observed pattern of growth in length of 48 individual boys and girls during the adolescent cycle of growth, *Hum. Biol.*, 29: 83-122, 1957.
10. Fanning, E. Effect of extraction of deciduous molars on the formation and eruption of their successors, *Angle Orthodont.*, 32: 44-53, 1962.
11. Flory, C. Osseous development in the hand as an index of skeletal development, Monogr. Soc. Res. Child Develop., Vol. I, No. 3, 141 pp., Committee on Child Develop., Univ. Chicago Press, 1936.
12. Francis, C. The appearance of centers of ossification from 6 to 15 years, *Amer. J. Phys. Anthropol.*, 27: 127-38, 1940.
13. Garn, S., Lewis, A., Koski, K., and Polacheck, D. The sex difference in tooth calcification, *J. Dent. Res.*, 37: 561-67, 1958.
14. Garn, S., Lewis, A., and Polacheck, D. Variability of tooth formation, *J. Dent. Res.*, 38: 135-48, 1959.
15. Garn, S., and Rohmann, C. The aductor sesamoid of the thumb, *Amer. J. Phys. Anthropol.*, 20: 297-302, 1962.
16. Gleiser, I., and Hunt, E. The permanent mandibular first molar: Its calcification, eruption and decay, *Amer. J. Phys. Anthropol.*, 13: 253-83, 1955.
17. Grøn, A. Prediction of tooth emergence, *J. Dent. Res.*, 41: 573-85, 1962.
18. Hewitt, D., and Acheson, R. Some aspects of skeletal development through adolescence. II. The inter-relationship between skeletal maturation and growth at puberty, *Amer. J. Phys. Anthropol.*, N.S. 19: 333-44, 1961.
19. Hubay, C. Sesamoid bones of the hands and feet, *Amer. J. Roentgenol.*, 61: 493-505, 1949.
20. Joseph, J. The sesamoid bones of the hand and the time of fusion of the epiphyses of the thumb, *J. Anat. (Lond.)*, 85: 230-41, 1951.
21. Lewis, A., and Garn, S. The relationship between tooth formation and other maturational factors, *Angle Orthodont.*, 30: 70-7, 1960.

22. Meredith, H. Relation between the eruption of selected mandibular permanent teeth and the circumpuberal acceleration in stature, *J. Dent. Child*, First Quarter: 75-8, 1959.
23. Moorrees, C., Fanning, E., Grøn, A., and Le Bret, L. The timing of orthodontic treatment in relation to tooth formation, *Europ. orthodont. Soc. Trans.*, 1962.
24. Moorrees, C., Fanning, E., and Hunt, E. Age variation of formation stages for ten permanent teeth, *J. Dent. Res.*, 42: 1490-1502, 1963.
25. Moorrees, C., and Reed, R. Changes in dental arch dimensions expressed on the basis of tooth eruption as a measure of biological age, *J. Dent. Res.*, 44: 129-41, 1965.
26. Nanda, R. The rates of growth of several facial components measured from serial cephalometric roentgenograms, *Amer. J. Orthodont.*, 41: 658-73, 1955.
27. Nanda, R. Eruption of human teeth, *Amer. J. Orthodont.*, 46: 363-78, 1960.
28. Nelson, W. *Textbook of pediatrics*, 8th Ed., Saunders Co., Philadelphia, 1964.
29. Nicolson A., and Hanley, C. Indices of physiological maturity: Derivation and interrelationships, *Child Development.*, 24: 3-38, 1953.
30. Pyle, I., Stuart, H., Cornoni, J., and Reed, R. Onsets, completions, and spans of the osseous stage of development in representative bone growth centers of the extremities, *Monogr. Soc. Res. Child Develop.*, No. 79, 126 pp., 1961.
31. Solow, B. The pattern of craniofacial association. A morphological and methodological correlation and factor analysis study on young male adults. *Acta odont. scand.*, 24: Suppl. 46, 1966.
32. Shuttleworth, F. Sexual maturation and the physical growth of girls age six to nineteen, *Monogr. Soc. Res. Child Develop.*, No. 5, 253 pp., 1937.
33. Shuttleworth, F. The physical and mental growth of girls and boys age six to nineteen in relation to age at maximum growth, *Monogr. Soc. Res. Child Develop.*, No. 3, 291 pp., 1939.
34. Tanner, J. *Growth at adolescence*, 2nd. Ed., Blackwell, Oxford, 1962.
35. Tanner, J., Whitehouse, R., and Healy, M. A new system for estimating skeletal maturity from the hand and wrist, with standards derived from a study of 2,600 healthy British children. Part II: The scoring system, *International Children's Centre*, Paris, 1962.