# The Relationship Between Tooth Formation and Other Maturational Factors

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The formation and eruption of the teeth in and through the jaws is a subject of importance to orthodontists as well as to workers in allied fields. Since x-rays have been used for over fifty years, one might expect tooth formation to have been studied more extensively than it has been during this time.

The material for our studies consists of a group of healthy, white, Ohio-born children, primarily of the middle socioeconomic class and enrolled in the longitudinal studies of growth and development at the Fels Research Institute, Yellow Springs, Ohio.

From this group we have been able to obtain serial oblique jaw radiographs of two hundred and fifty-five children and a tremendous amount of information on somatic and sexual growth and development, on biochemical functioning, on behavior, personality and on health and disease. Some of these data are now being viewed in connection with the material on tooth formation in an effort to determine the various endogenous and exogenous factors that affect the tempo of dental development, patterning differences, and the extent of sexual dimorphism. Since the oblique jaw x-ray is the source of our data, our observations are confined to the mandibular posterior teeth.

We have endeavored to set up various stages of tooth calcification and tooth movement, to learn the sequence of such events, to determine sex differences in, and variations of, tooth formation and finally, the degree to which dental maturation relates to general growth and development.

## STAGES

It is obvious that many stages of tooth formation could be used. Various workers have estimated the proportions of crown and root formation by the quarters; others have utilized as many as twenty stages for a tooth. We have chosen, to date, to adhere to a relatively simple system of stages. These stages are: 1) beginning calcification of the crown, 2) completion of crown formation and 3) apical closure (Fig. 1). In addition to the above, we have recognized two movement stages: 1) alveolar eruption, the time at which there is no apparent alveolar bone over the tooth and 2) the attainment of the occlusal level.

## SEQUENCE

In one of our earlier studies we found that $M_1$, $P_1$ and $M_3$ invariably showed initial calcification first, second and last respectively. $P_2$ and $M_2$ varied in order of appearance and in some children began to calcify at the same time. Siblings of the $P_2$ $M_2$ children tended to the $P_2$ $M_2$ sequence and siblings of the $M_2$ $P_2$ children to the $M_2$ $P_2$ sequence more often than would be expected on a chance basis. Youngsters with $P_2M_2$ formation sequence erupted their teeth in that order but

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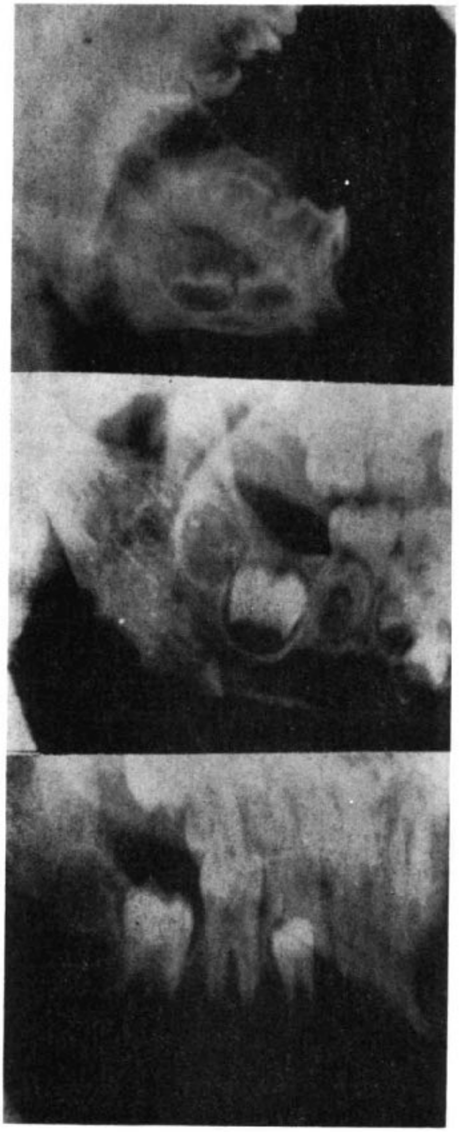

Fig. 1. Top, Beginning calcification of $M_1$. Middle, crown completion of $M_1$. Below, Apical closure of $M_1$, and alveolar eruption of $M_2$.

one-half of the $M_2P_2$ reversed their order.

## Sex Differences

The fact that teeth are earlier in eruption in girls than boys and the further possibility of the hormonal factor affecting eruption lead us to compare formation time in the two sexes.

In general, girls were advanced over boys by an average of 0.32 years and by amounts up to 0.92 years. This sex difference is of the same order of magnitude as the sex difference observed in tooth eruption by Gleiser and Hunt from Hurmes' data. However, sex differences in dental development, while marked, are of a lesser order of magnitude than the degree of sexual dimorphism in osseous development. Figure 2 demonstrates the sex differences in tooth formation, tooth eruption, ossification in the knee and in thirty-six ossification centers in the shoulder, upper arm, hand, hip, knee and foot.

The standards of Pyle and Hoerr were used for knee ossification and those of Sontag and Pyle, and Sontag and Reynolds for the other centers. The large black dots show sex differences in tooth formation, the open circles the sex differences in knee ossification. Only lines of slope are shown for tooth eruption and the thirty-six bone centers. When the differences are related to age, girls are about three per cent ahead of the boys throughout. This value approximates the sex dif-

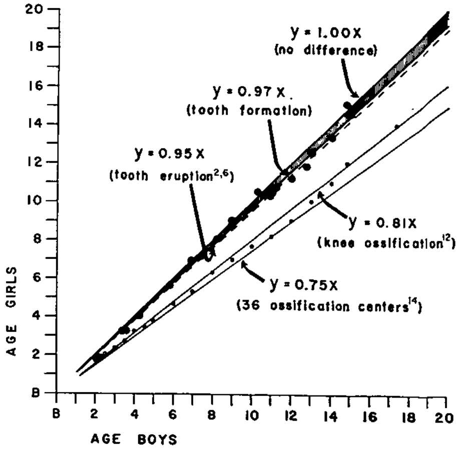


Fig. 2.

ference in eruption, but is, of course, much smaller than the nineteen per cent difference in the knee and the twenty-five per cent difference in the appearance of thirty-six ossification centers.

### Variability

One important part of our findings concerns the variability of tooth formation. Specifically, we refer to the range of ages between which a given state of formation is found. For this particular work the two stages of movements were not calculated and the sexes were combined. Most contemporary references to tooth formation and its variability are derived directly or indirectly from the studies of Logan and Kronfeld in 1933 and from the tables of Kronfeld published in 1935. Their sample numbered twenty-five with only nine infants over one year of age and half less than three months of age at the time of death.

As soon as we began to compare our data with the Logan and Kronfeld tables as amended, altered, and condensed by many authors, we found their ranges far too narrow, being on the average one-third of the "true" range for any of the mandibular posterior teeth. Apparently the very limited number of cases available to Logan and Kronfeld was inadequate to provide a picture of the true variability of tooth formation.

It is possible that data derived from histologic sections are not at all comparable to roentgenographic findings. This objection would be most applicable to beginning calcification and least applicable to apical completion. Nevertheless, the discrepancies between our findings and theirs apply equally to beginning calcification, completion of crown formation and to apical closure. Moreover, it is ranges and not mean or median values that are under comparison. It is possible that the ranges are defined differently, for neither Logan and Kronfeld, nor Kronfeld are explicit on this matter. But if their ranges truly cover the extreme range, our fifth to ninety-fifth percentile ranges should fall short of theirs. The converse is true, however, as can be seen in Table I. The differences between the ranges given here and those in the literature, quite apparent in this table, are graphed in Figure 3. Using the Kronfeld table for comparison the ranges of variability in the literature are approximately one-third as great as ours.

With this fact in mind it seemed desirable to compare dental variability with the variability of other commonly measured maturational factors such as eruption of deciduous and permanent teeth, time of appearance of the first sixty-one centers of bone ossification, hand or wrist age, and age at menarche. Except for permanent tooth eruption and wrist age all data on variability were derived from our present population sample. Since developmental phenomena covering eighteen years had to be compared, the use of the coefficient of variation was adopted.

All values were corrected to conception, rather than to birth, since the latter procedure resulted in spurious high values of the coefficient of variability for the earliest developing phenomena. Accordingly, a group correction of .75 years was added to all values. As can be seen in Figure 4, tooth formation proved no more variable and often less variable than the age-developmental variability of menarche, tooth eruption, hand age or the appearance of ossification centers. Under these circumstances we believe that tooth formation affords a more definitive and useful estimate of chronological age in children of white ancestry when this is not known.

TABLE I

VARIABILITY OF $\overline{P_1}$—$\overline{M_3}$ AS GIVEN BY VARIOUS AUTHORS

| Mandibular Tooth | Logan and Kronfeld | Kronfeld, Holt and Mc Intosh, Wilkins | Schour and Massler, Arey | Spector | This Study (Percentiles 5th—95th) |
|---|---|---|---|---|---|
| | | *Beginning Calcification (Years)* | | | |
| $P_1$ | 1.50—2.00 | 1.75— 2.00 | 1.50— 2.00 | 1.75 | 1.6— 3.0 |
| $P_2$ | 2.00—2.50 | 2.25— 2.50 | 2.00— 2.50 | 2.50 | 2.7— 4.7 |
| $M_1$ | 0.08—0.33 | Birth | Birth | Birth | 0.04— 0.24 |
| $M_2$ | 2.00—2.50 | 2.50— 3.00 | 2.50— 3.00 | 2.75 | 2.8— 4.8 |
| $M_3$ | 7.00—9.00 | 8.00—10.00 | 7.00—10.00 | 7.00—10.00 | 7.5—10.9 |
| | | *Crown Completion—(Years)* | | | |
| $P_1$ | .... | 5.00— 6.00 | 5.00— 6.00 | .... | 6.0— 8.1 |
| $P_2$ | .... | 6.00— 7.00 | 6.00— 7.00 | .... | 6.7— 9.3 |
| $M_1$ | .... | 2.50— 3.00 | 2.50— 3.00 | .... | 3.1— 4.9 |
| $M_2$ | .... | 7.00— 8.00 | 7.00— 8.00 | .... | 7.3—10.2 |
| $M_3$ | .... | 12.00—16.00 | 12.00—16.00 | .... | 12.0—17.1 |
| | | *Apical Closure (Years)* | | | |
| $P_1$ | .... | 12.00—13.00 | 12.00—13.00 | 12.00—13.00 | 11.2—14.0 |
| $P_2$ | .... | 13.00—14.00 | 12.00—14.00 | 12.00—14.00 | 12.1—15.4 |
| $M_1$ | .... | 9.00—10.00 | 9.00—10.00 | 9.00—10.00 | 8.8—11.6 |
| $M_2$ | .... | 14.00—15.00 | 14.00—16.00 | 14.00—16.00 | 12.8—17.6 |
| $M_3$ | .... | 18.00—25.00 | 18.00—25.00 | 18.00—25.00 | Under 18 to over 26 |

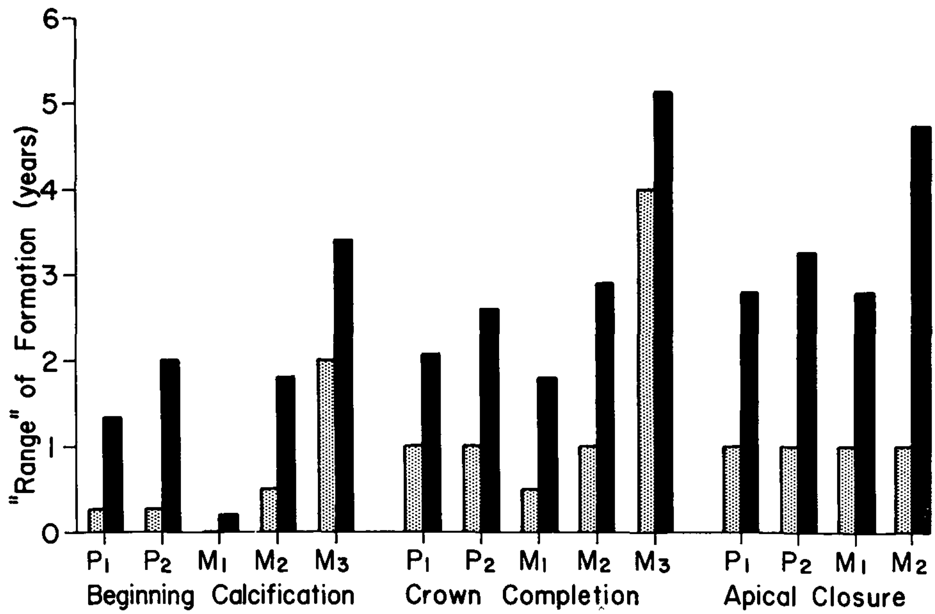


Fig. 3

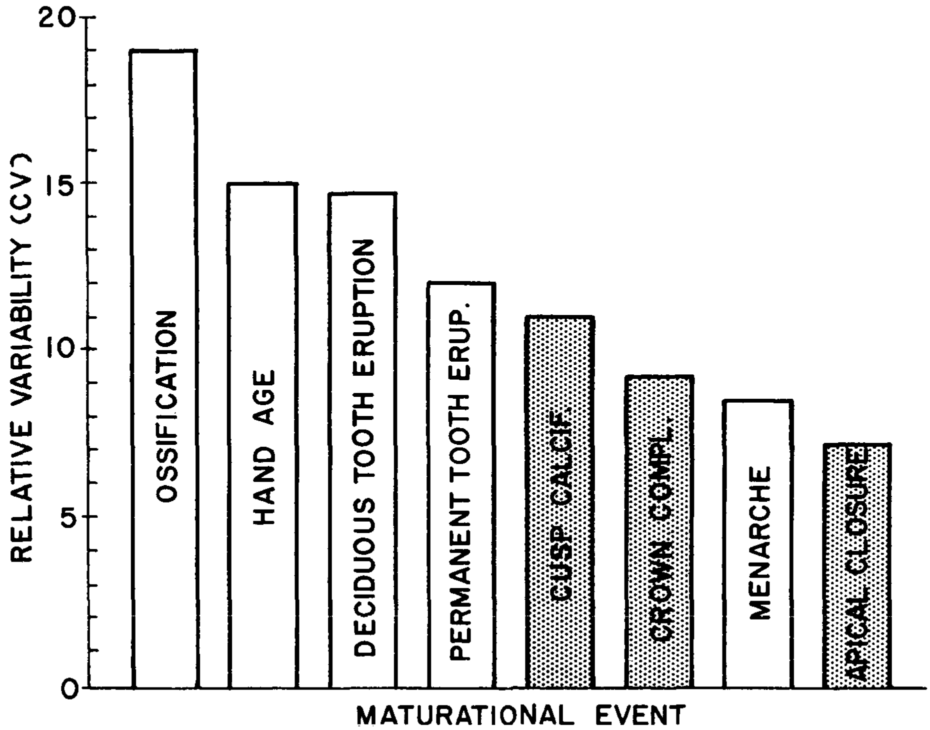


Fig. 4

## Genetics and Tooth Formation

From our analyses of monozygotic and dizygotic twin pairs and siblings of both sexes we believe that tooth formation, to a large extent, is gene-determined. In monozygotic twin pairings correlations of tooth formation range from 0.75 to better than 0.9. Correlations among dizygotic pairings from triplet sets approximate 0.3, the same order of magnitude as sibling correlation. These findings are consistent with the hypothesis that the timing of tooth formation is largely, but not necessarily exclusively, gene-determined. This is the same conclusion we reached earlier with respect to the formation sequences of $P_2$ and $M_2$.

## Interrelationships

We have examined interrelationships in tooth formation in considerable detail. This has been a lengthy task since we have used five stages for five teeth for two sexes. We have found that intercorrelations involving tooth calcification stages alone and tooth movement stages alone are higher than those relating tooth calcifications to tooth movement. In addition, we have correlated tooth formation with such variables as stature, weight, subcutaneous fat thickness, bone age, menarche in girls and the time of epiphyseal union of the tibia in both sexes in order to determine the relationship of nutritional status, size and sexual maturation to the rate of tooth formation. Studies in this area are still in progress and only part of our findings are summarized here.

During infancy and childhood interrelationships between tooth formation and general growth and development, though positive, are low and rarely

TABLE II

CORRELATIONS BETWEEN TOOTH FORMATION AND OSSEOUS DEVELOPMENT, STATURE, WEIGHT AND FAT THICKNESS

| Tooth and Stage of Development | | Measure of Growth or Nutrition | Age | No. | Correlation | Significance Level |
|---|---|---|---|---|---|---|
| $M_2$ | Beginning Calcification | No. of hand-wrist centers | 3.5 | 98 | 0.033 | NS |
| $M_2$ | Crown Completion | "Bone Age" (Greulich & Pyle) | 9.0 | 100 | —0.274[1] | 0.05 |
| $M_3$ | Beginning Calcification | "Bone Age" (Greulich & Pyle) | 9.0 | 83 | —0.305 | 0.01 |
| $M_2$ | Beginning Calcification | Thoracic fat | 3.5 | 54 | —0.030 | NS |
| $P_1$ | Beginning Calcification | Height | 2.0 | 150 | —0.114 | NS |
| $P_1$ | Beginning Calcification | Weight | 2.0 | 151 | —0.111 | NS |
| $P_1$ | Crown Completion | Height | 7.5 | 167 | —0.262 | 0.01 |
| $P_1$ | Crown Completion | Weight | 7.3 | 166 | —0.171 | 0.05 |
| $M_2$ | Occlusal Level | Height | 12.3 | 43 | —0.262 | NS |
| $M_2$ | Occlusal Level | Weight | 12.3 | 43 | —0.231 | NS |

[1] i.e. children advanced (9 or earlier) in tooth formation have, at a uniform age, a higher bone age, hence the negative correlation.

significant. In Table II are noted some relationships between tooth formation and stature, weight, number of carpal centers, bone age and fat. In general we can report a relationship and in the expected direction. The correlations from infancy through early adolescence are far from high, averaging about 0.2. Correlations with the number of carpal centers during the first few years of life and with bone age (Greulich and Pyle ) in preadolescence similarly suggest osseous advancement associated with dental maturation. Although fatter boys and girls in the Fels series are demonstrably taller and advanced in bone age, they are only slightly and not significantly ahead in tooth formation.

As adolescence approaches, there is an increasing association between maturational status and tooth formation. Using menarche as a measure of sexual maturation in girls and tibial union (the age at union of the proximal epiphyses of the tibia) in both sexes, we have investigated the timing of these phenomena in relation to the timing of tooth formation and movement. As shown in Table III, sexual maturation is more highly correlated with tooth formation and especially tooth movement, than proved true of

TABLE III

CORRELATIONS BETWEEN SECOND MOLAR DEVELOPMENT AND SEXUAL AND OSSEOUS MATURATION

| | Tooth and Stage of Development | Correlated with Age at | Sex | No. | Correlation | Significance Level |
|---|---|---|---|---|---|---|
| $M_2$ | Crown Completion | Menarche | f | 63 | 0.335 | 0.01 |
| $M_2$ | Alveolar Eruption | Menarche | f | 35 | 0.621 | 0.001 |
| $M_2$ | Occlusal Level | Menarche | f | 35 | 0.614 | 0.001 |
| $M_2$ | Apical Closure | Menarche | f | 15 | 0.287 | NS |
| $M_2$ | Crown Completion | Tibial union | m&f | 101 | 0.265 | 0.05 |
| $M_2$ | Alveolar Eruption | Tibial union | m&f | 45 | 0.511 | 0.001 |
| $M_2$ | Occlusal Level | Tibial union | m&f | 26 | 0.544 | 0.01 |
| $M_2$ | Apical Closure | Tibial union | m&f | 28 | 0.338 | 0.05 |

somatic growth. Correlation between certain stages of tooth formation or movement and menarche reached as high as 0.62 while correlation with tibial union ranged from 0.12 to 0.54 in both sexes with an average of 0.40 for thirty-six correlations.

While it is obvious that the teeth are not unusually accelerated or retarded in their development when growth is faster or slower, the explanation for the relationships between dental formation and general maturation requires further investigation. It is evident from clinical studies that tooth eruption is accelerated in early-maturing girls; this leads to the possibility that to some extent steroid hormones of gonadal and adrenal origin may be involved in the relationship between sexual maturation and dental development.

We are now working with a pediatric endocrinologist in an attempt to evaluate the effects of certain endocrinopathies on the development of the teeth. While we thought advanced dental maturation to be associated with certain endocrinopathies and retarded dental maturation with others, we now believe that additional information must be gathered before we can say anything definite about the hormones involved or their effects on tooth formation.

*Fels Institute*

BIBLIOGRAPHY


1. Black, G. V.: Operative Dentistry, *Medico-Dental Publishing Co.*, Chicago, 1908.
2. Broadbent, B. H.: Ontogenetic Development of Occlusion, *Angle Ortho.*, 11: 223, 1941.
3. Churchill, H. R.: Human Odontography and Histology, *Lea and Febiger*, Philadelphia, 1932.
4. Garn, S. M., A. B. Lewis and D. W. Shoemaker: The Sequence of Calcification of Molar and Premolar Teeth, *J.D.Res.*, 35:555, 1956.
5. Garn, S. M. and A. B. Lewis: Relationship Between the Sequence of Calcification and the Sequence of Eruption of Mandibular Molar and Premolar Teeth, *J.D.Res.*, 36: 992, 1957.
6. Garn, S. M., A. B. Lewis, K. Koski and D. L. Polacheck: The Sex Difference

in Tooth Calcification, *J.D.Res.*, 37: 561, 1958.
7. Garn, S. M., A. B. Lewis and D. L. Polacheck: Variability of Tooth Formation, *J.D.Res.*, 38: 135, 1959.
8. Garn, S. M., A. B. Lewis and D. L. Polacheck: Interrelations in Dental Development, *J.D.Res.*, 39: in press, 1960.
9. Hess, A. F., J. M. Lewis and B. Roman: A Radiographic Study of Calcification of the Teeth from Birth to Adolescence, *Dental Cosmos*, 74: 1053, 1932.
10. Kronfeld, R.: Development and Calcification of the Human Deciduous and Permanent Dentition, *The Bur*, 35: 18, 1935.
11. Legros, C., and E. Magitot: The Origin and Formation of the Dental Follicle, *Jansen, McClurg and Co.*, Chicago, 1880.
12. Logan, W. H. G. and R. Kronfeld: Development of the Human Jaws and Surrounding Structures from Birth to Fifteen Years, *J.A.D.A.*, 20:379, 1933.
13. Pierce, C. N.: Calcification and Decalcification of the Teeth, *Dental Cosmos*, 26: 449, 1884.
14. Schour, I. and M. Massler: Studies in Tooth Development, *J.A.D.A.*, 27:1918, 1940.
15. Spector, W. S.: Handbook of Biological Data, *W. B. Saunders Co.*, Philadelphia, 1956.

## Discussion

### Dr. John W. Richardson

In discussing this very comprehensive study of tooth maturation I can only admire the detail into which Dr. Lewis has gone, and hope that I can be helpful to him. He has included sex differences, the similarity of siblings and the actual eruption of the permanent teeth — the order of which I had always felt had no rhyme or reason.

The Bolton Fund has graciously released to me some material from many years ago and may I point out that one of the first standards that they published was the table showing the time of beginning calcification of the permanent teeth. This served as a rough method of assessing skeletal age from birth to the ninth year.

In 1940 I was assigned the problem of collaborating with Dr. Carl Francis, of the Brush Foundation, on the program of the A.D.A. Dr. Francis presented five cases analyzed as to growth and development from the long bone and joint viewpoint. My part was to compare his findings with those of the cephalometer.

After a review of a number of series judged by the Bolton and Brush groups as being normal, I established a graph to determine the skeletal age from shortly after birth until nearly adulthood. To apply this to a given individual a standardized cephalometric x-ray is taken, the total amount of calcification of the permanent dentition in one quadrant is measured and the number of centimeters is applied to the chart. (Slide) Where the measurement crosses the white line on the graph indicates the individual's skeletal age. This technique seemed to give answers very similar to those of Todds' *Atlas of Skeletal Maturation.*

It is possible that if Dr. Lewis arranged his material in the order of skeletal age, rather than chronological age some of his variables might be lessened.