Skeletal Maturation And Cephalofacial Development[1]

FRANCIS E. JOHNSTON, Ph.D.[2]
H. PAUL HUFHAM, JR., D.M.D.
ANTHONY F. MORESCHI, D.D.S.
GENE P. TERRY, D.D.S.
Philadelphia, Pa.

The establishment of the skeleton as that area which best provides a general estimate of the degree of maturity in a particular child now seems complete. Though there are methodological differences (Acheson, 1954; Greulich and Pyle, 1959) this approach enjoys a widespread use in both clinical and research areas. However, in spite of the fact that skeletal maturation is commonly used and that much more accurate predictions of events such as mature height (Bayley and Pinneau, 1952) and menarche (Simmons and Greulich, 1943) are possible, there remains a significant lack of correlation of other growth events and measures of biological time for the purpose of determining similar relationships.

Questions of this sort have a direct clinical application within the dental profession; e.g., to what extent is disharmonious cephalofacial development related to variations from normal maturation rates? It is the purpose of this paper to report on a series of studies relating to this problem in an attempt to demonstrate the existence of such a relationship, and to suggest some of the inherent clinical implications.

Previous studies have failed to demonstrate relationships of a useful nature. Hellman (1932) was one of the first to recognize the importance of developmental age, grouping children by eruptive stage rather than chronological age. However, the many extrinsic factors operating to cause variation in eruptive time and sequence make it largely unsatisfactory as an indicator of maturation level (Gray and Lamons, 1959; Green, 1961). Some studies (Moss and Greenberg, 1956; Hughes, 1958; Seide, 1961; Burstone, 1963) have postulated relationships between cephalofacial development and skeletal maturation, but not conclusively. Bambha and Van Natta (1959) have concluded that malocclusion cannot be related to maturation differential, while Rose (1960) found no correlation between facial growth and skeletal maturation. It is felt, however, that neither of these two studies can be regarded as conclusive due to the research designs. The former treated a complex series of occlusal disharmonies with a variety of etiologies and manifestations as though they could be grouped into the standard three categories of the Angle classification. We feel that, e.g., a Class II malocclusion, though a clinical reality, represents a heterogeneous collection and its unqualified use in a research problem might conceivably cover up important differences. An attempt to elicit these differences has been made in this paper. The paper by Rose, in which he failed to find relationships between carpal development and certain areas within

1. Supported, in part, by U. S. P. H. S. Grants D-00087 (1-15).

2. Philadelphia Center for Research in Child Growth and Department of Orthodontics, University of Pennsylvania School of Dentistry.

the face, failed to differentiate between those components of growth which determine ultimate size and those which determine the rate at which that size is attained. What Rose actually demonstrated was that generally big children tend to have big faces.

It therefore appears that the existing literature suffers from the double handicap of a paucity of studies as well as a lack of conclusive results. We may say that the suggestions of Burstone (1963), though attractive, remain largely unproven.

Material and Methods

The present paper consists of three separate studies, all carried out on children of similar backgrounds, ages, dental and medical health. Each study had the same purpose: does skeletal maturation play a part in cephalofacial development which makes its use desirable as an indicator of maturation level? The children were all Caucasoid and judged clinically normal; they were selected from area schools as part of a survey of growth in Philadelphia children by the *Growth Center,* W. M. Krogman, director, between 1947-1962. The determinations of skeletal maturation were made by assigning a skeletal age (a developmental equivalent) average for each set of observations utilizing the inspectional technique and the Greulich and Pyle (1959) Atlas.

Study Number One

In this study skeletal age as a predictor of the percentage of completed growth in particular dimensions was analyzed and compared with chronological age used in the same way. This approach has been successfully used for stature by Bayley (1943), and is the basis of the tables for prediction of adult stature (Bayley and Pinneau, 1952). Using percentage of adult size (i.e., of completed growth) in a child eliminates individual differences in adult size and permits a concentration upon biological time as a measure of completed growth.

A sample of twenty white girls was selected from the *Growth Center* normal series, as discussed above. The criteria for selection were, (1) the availability of longitudinal records and, (2) a Class I dental occlusion, essentially normal, as evaluated from dental casts taken at the various examinations. The ages ranged from 10.5-18.0 years, and the data were mixed longitudinal in nature. The maximum time between any two visits was two years; the total number of examinations was 202. Measurements were made to the nearest half-millimeter from lateral x-rays taken in a Broadbent-Bolton roentgenographic cephalometer under standard conditions (Krogman and Sassouni, 1957). Table 1 lists the dimensions taken, landmarks being defined as in Krogman and Sassouni.

Since the observations did not include children older than 18 years, their adult dimensions were not determinate for every measurement; for this reason the sample was restricted to girls, their growth periods ending approximately two years earlier than boys. The value for 16.5 (interpolated, if necessary) was chosen as "mature" and considered to be one hundred percent. The percentage of this amount achieved at half-year intervals was computed for both skeletal and chronological ages for all

Table 1
Measurements

sella-nasion
sella-prosthion
sella-gnathion
nasion-prosthion
nasion-gnathion
articulare-prosthion
articulare-gonion
gonion-gnathion

twenty girls. Mean percentages and standard deviations were computed as well as differences in the measures of variation.

It was noted that all dimensions showed mean increases beyond the "mature" point of 16.5 years, both CA and SA. These increases were quite small however, and, for chronological age, were all less than 1.0%. The increases beyond a skeletal age of 16.5 were larger, the maximum being 1.3% except for articulare-gonion which averaged 102.5% of the "mature" value at 18.0 years. In terms of actual increment, however, these post - 16.5 increases were quite small and not considered significant in this study.

The resulting means of percentage of completed growth were computed for chronological and skeletal ages. A comparison of the means for equivalent SA and CA showed that, while SA-values were less, statistically-significant differences occurred in only a few random cases. On the other hand, at every age, the mean SA value was less than that for CA. This smaller value is most likely due to the fact that Philadelphia girls, after the onset of puberty, are generally advanced in SA relative to the Greulich and Pyle standards (Johnston, 1963).

A better evaluation of the effects of using a measure of biological maturation *in lieu* of chronological age can be gained by an examination of the relative values of the associated variances. At no time, when the children were grouped by skeletal age, was the variance for a particular dimension significantly less than when they were grouped by chronological age. However, the variance, at all ages, showed a consistent tendency to be less for certain dimensions. This tendency was analyzed statistically by means of a Wilcoxen non-parametric test (Siegel, 1956) which tested this consistency for the variance to be less in SA-grouping. The results are given in Table 2. It can be seen that three dimensions stand out with relation to skeletal age. Since grouping by this measure of maturation level reduces the associated variance, we may say that they are more closely related to skeletal age. They are articulare-gonion, gonion-gnathion, and sella-nasion. The first two correspond to ramal and corpal lengths of the mandible and indicate a close relationship between mandibular and general skeletal growth patterns. The sella-nasion dimension would seem to contradict the traditional concept of stability for this line and would indicate that there are spurts of growth there corresponding to those of the skeleton generally. Nasion-prosthion, sella-prosthion, and sella-gnathion showed closer relationships to SA but not at statistically-significant levels. On the other hand, nasion-gnathion and articulare-prosthion are more closely related to chronological age, but only the latter significantly so.

Table 2

Results of Statistical Analysis of Variation Reduction in SA-Grouping

	Significant	*Not Significant*
SA-Variance Usually Less	articulare-gonion sella-nasion gonion-gnathion	nasion-prosthion sella-prosthion sella-gnathion
CA-Variance Usually Less	nasion-gnathion	articulare-prosthion

These relationships are not too surprising from a growth-oriented point of view. Articulare-prosthion and nasion-gnathion cross so many growth loci and are generally so unrelated to any known growth axes as to be unreliable as measures of specific growth. Those that are significantly related to SA are generally more related to actual directions of growth. The intermediate dimensions vary in either direction. This again emphasizes the necessity, when studying growth, of utilizing dimensions which involve as few centers as possible, and which move parallel to known axes.

The closer relationship of mandibular rather than midfacial dimensions indicates that individual variation in skeletal age is more closely related to variation in mandibular growth than to other aspects. This raises the question of differential facial patterns being ultimately related to variation in individual rates of growth.

Study Number Two

This study, anthropometric rather than roentgenographic cephalometric, was carried out on a mixed longitudinal sample of normal healthy children between the age of 7-17 years. The number studied was 62 female and 58 male, all white; the total number of visits was 976, averaging slightly over 8 per child. The results have been previously reported (Johnston, 1964), but certain aspects are worthy of repetition in this framework and from a more clinical point of view. The anthropometric dimensions are given in Table 3.

Mean values were calculated for each dimension at even year intervals for both skeletal and chronological age, as were mean skeletal ages for each chronological age group. The differences between SA and CA were correlated, for each dimension, with the differences between the CA and SA-grouped means. If SA increased beyond CA by a given amount, the mean for a given dimension when grouped by SA would be *less* than the CA-mean (if there was a close relationship). This is due to the fact that, as SA became larger relative to CA, the SA-grouped means would represent children of lower CA's. For this reason all coefficients of correlation are negative, but this is an artifact of the experimental design. High values indicate relationships of a positive nature, regardless of the sign. The results are presented in Table 4.

Table 3
Anthropometric Dimensions

bizygomatic breadth (zy-zy)
bigonial breadth (go-go)
total face height (na-gn)
upper face height (na-supradentale)
lower face height (infradentale-gn)
ramal height (cond-go)
porion-nasion
porion-subnasale
porion-gnathion
condylion-gnathion
gonion-gnathion

It can be seen that significant relationships exist between certain cephalometric dimensions and skeletal age. The sex differences, though not statistically significant in any single case, still indicate higher values for girls. The lower values for boys may be due to their more intense adolescent spurt resulting in greater dimensional variability and consequently lower r-values.

Further insight suggested by the previous study can be gathered concerning the relationships in the mandible by analyzing the three intrinsic measurements that were taken which reflect growth in basically an antero-posterior direction. Table 4 shows that these three dimensions, within each sex, have their coefficients of correlation in

Table 4

Correlation Between Mean SA Increment and Mean Growth Increment. (n=11)

M		F	
Bizygomatic	—.660*	Gonion-gnathion	—.833**
Porion-gnathion	—.626*	Condylion-gnathion	—.790**
Lower Face Ht.	—.624*	Bizygomatic	—.767**
Gonion-gnathion	—.566	Porion-gnathion	—.674*
Total Face Ht.	—.551	Ramal Ht.	—.622*
Bigonial	—.535	Upper Face Ht.	—.557
Upper Face Ht.	—.482	Total Face Ht.	—.556
Condylion-gnathion	—.405	Lower Face Ht.	—.487
Ramal Ht.	—.381	Porion-nasion	—.426
Porion-subnasale	—.377	Bigonial	—.413
Porion-nasion	—.184	Porion-subnasale	—.360

* — significant at $p < .05$
** — significant at $p < .01$

the same positions relative to value: gonion - gnathion, condylion - gnathion, and condylion-gonion. In addition, treating this aspect of mandibular growth as a triangle, they collectively contain three end points. Table 5 groups these measurements by the common landmarks in each and presents the average of the grouped *r*'s. It can be seen that the average *r* is the highest where gnathion is the common landmark, while those involving condylion yield the lowest means. This points to the chin as a focal area for SA relationships in both sexes. The lowered values for the condyle cannot be readily explained, but may reflect the high degree of observer variability implicating this point, and the resulting high degree of error due to technical difficulties. It is interesting to note, however, that values for the condyle were close to those reported for stature (Johnston, 1964), which has been shown (Bayley and Pinneau, 1952) to have a high predictability if the skele-

Table 5

Analysis of Mandibular Growth

Dimension	M r	M $\bar{r}$	F r	F $\bar{r}$	Common Factor
Condylion-Gnathion	.405		.790		
		.486		.812	Gnathion
Gonion-Gnathion*	.566		.833		
Condylion-Gonion**	.381		.622		
		.474		.728	Gonion
Gonion-Gnathion*	.566		.833		
Condylion-Gonion**	.381		.622		
		.393		.706	Condylion
Condylion-Gnathion	.405		.790		

* — Length of Mandibular Corpus
** — Height of Mandibular Ramus

Table 6
SNA, SNB, and ANB Values for Philadelphia and Chicago Children.

Source	Age	n	SNA Mean	SNA 1-½ S.D.	SNB Mean	SNB 1-½ S.D.	ANB Mean	ANB 1-½ S.D.
Philadelphia[1]	12.63	70	83.2°	5.0	79.3°	5.0	+3.9°	2.7
Chicago[2]	8-11		80.8	5.7	78.0	4.5	+2.8	3.5
Chicago	18		82.0	5.7	80.0	5.7	+2.0	2.7

1 — Philadelphia values from Ianantuoni (1962)
2 — Chicago values from Riedel (1952)
3 — Mean age of children all exhibiting Hellman IVA eruptive stage.

tal age is taken as the measure of age.

This second study again points out certain differential relationships between skeletal age and cephalofacial growth which carries with it implications to be discussed in later sections of this paper.

Study Number Three

This study investigated the possibility of a relationship between skeletal age and dental occlusion. This was based on the hypothesis that, if certain dimensions were more closely related to skeletal age than others, then, as SA deviated from CA in a particular child, this differential might be expressed as a higher frequency of malocclusion. Due to the inconclusive results of the study by Bambha and Van Natta (1959) certain refinements in the study sample were made.

The first of these refinements involved separating those malocclusions (in this case, Class II, Division I) which involved facial disharmonies from those that seemed due to dental elements alone. Such a separation was based upon the angles SNA, SNB, and ANB, as measured from the lateral radiographs (Riedel, 1952). Standard values for these dimensions were obtained from a previous study by Ianantuoni (1962) and verified by Zung (1964); the differences from those found by Riedel were enough to justify their use in this study. The limits of normality were selected as plus and minus one and one-half standard deviations, thereby including about 87% of the normal population. These values are presented in Table 6, along with Riedel's.

It was also necessary to consider the fact that Philadelphia children are advanced in SA compared with the Greulich and Pyle standards (Johnston, 1963). Since the average child would therefore be "ahead", the expected SA would not be the CA, and it became necessary to compute the "expected SA". This was done by adding .07 years to each female CA, and .45 years to each male. These values represent the average advancement, at this age, of Philadelphia children.

The study sample consisted of 81 boys, age 12.5-13.5 years, and 56 girls, 10.5-11.5 years; different ages were used for the sexes to approximate equal growth stages. All of the children possessed Class II, Division 1 malocclusion. Utilizing the angular values of Table 6, these children fell into six groups as listed in Table 7. Representative tracings are presented in Figures 1-6.

An examination of Table 7 permits an evaluation of its categories with respect to the structures involved. Immediately apparent is that no children were found who had a value for either angle SNA or SNB greater than a plus 1½ s.d. Maxillary protrusion, as as-

Table 7
Grouping of Study Sample According to Angular Values.

Group	n M	n F	SNA	SNB	ANB
I	34	22	within[1]	within	within
II	14	9	within	within	greater
III	5	1	within	within	less
IV	13	12	within	less	greater
V	9	11	less	less	within
VI	6	1	less	less	greater
	81	56			

1 — The terms within, greater, and less refer to the range of plus and minus 1½ standard deviations.

sessed by SNA, does not seem to be as great a factor in Class II malocclusion as retrusion of the mandible, fifty-two out of the total sample of 137 displaying values for SNB of less than the acceptable limit for this study. There is some sex difference in the number with SNB values less than the normal range; the study sample is 59% male, but the categories consisting of SNB values that are "less" are only 53% male. This difference is not statistically significant, however, as shown by a x^2 square test.

Groups I and V undoubtedly represent malocclusions which are almost wholly dental in nature with balanced SNA-SNB values. Likewise, Groups II and VI probably contain largely "dental" malocclusions. SNA and SNB are within normal limits but, due to tendencies to fluctuate toward the opposite extremes of these limits, the A-B differences are greater than normal. It is

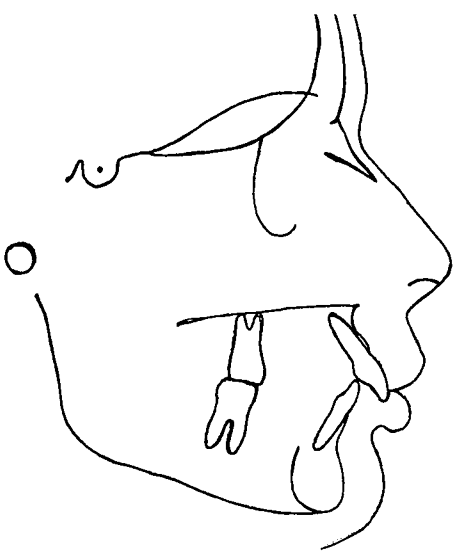

Fig. 1 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group I.

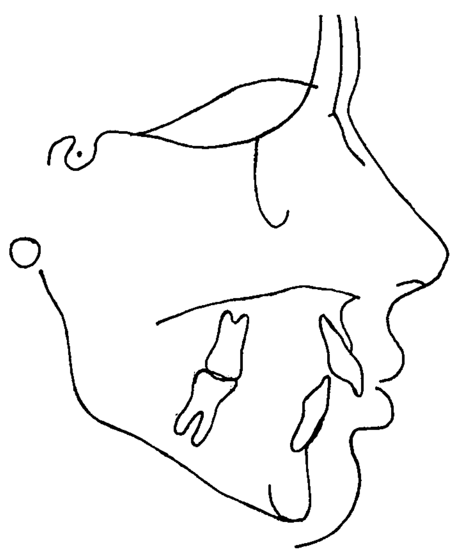

Fig. 2 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group II.

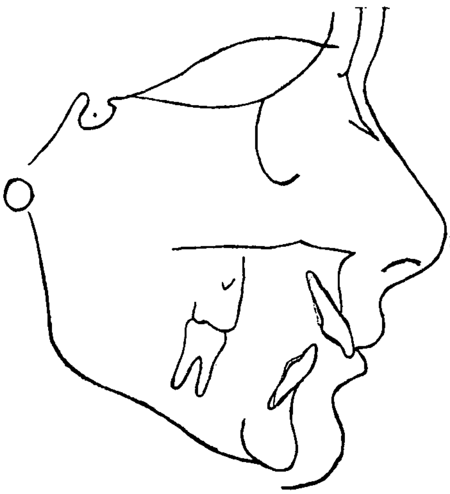

Fig. 3 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group III.

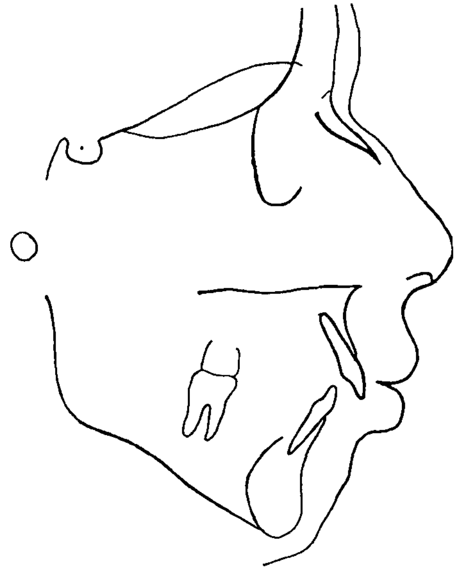

Fig. 4 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group IV.

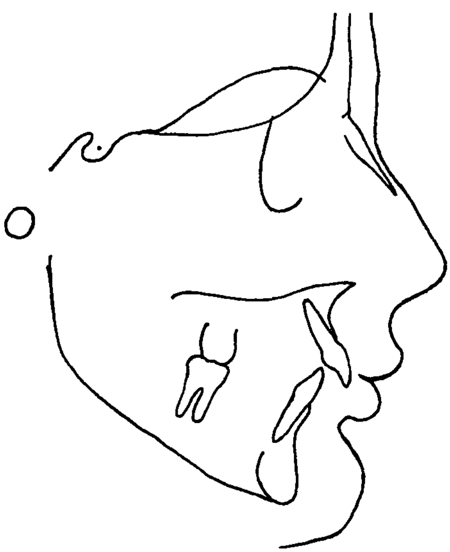

Fig. 5 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group V.

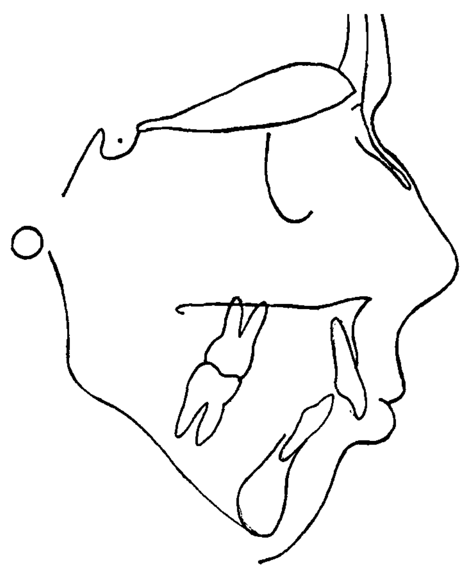

Fig. 6 A sample tracing selected to approximate the mean values obtained for SNA, SNB, and ANB in Group VI.

true that some cases of "skeletal" malocclusions occur in these groups but, for this study, the emphasis is upon skeletal malocclusions, and it was deemed advisable to design the categories in such a way that those designated skeletal contain *only* malocclusions of this type. (This is another way of recognizing that grouping errors must always occur, but must be controlled.) Group III may also be classed as dental. This leaves Group IV as the one group which is most likely to be made up of children with Class II malocclusions which are primarily skeletal in nature: a normal SNA angle, but SNB less and ANB greater than normal, presumably indicative of mandibular smallness and/or retrusion. Thus, these six groups may be classed as follows:

malocclusions purely skeletal
  Group IV
malocclusions dental and skeletal
  Groups II and VI
malocclusions purely dental
  Groups I, III, and V

Expected skeletal ages were compared with actual for each group. Mean differences were tested for significance by computing t-values. The results are presented in Table 8.

It can be seen that the only significant differences between SA and CA exist in the only group in which the malocclusions are presumably purely skeletal; the mean SA is retarded in this group. The groups with both skeletal and dental malocclusions ranked as almost significant ($p < .10$). Of the three dental categories, one was near significance; in the other two the probability of significant differences was no greater than fifty per cent. Thus it appears that maturational retardation is a factor in a Class II malocclusion insofar as skeletal factors are concerned.

Discussion

The processes of skeletal growth and maturation are composites which are under the control of a great many mechanisms, genetic, endocrinic, environmental, and functional. Individual growth dimensions and centers increase in size at varying rates with the result that the growing child is continually changing in body proportions until maturity is reached. The same is true for the cephalofacial complex as well, with some parts undergoing differential rates of increase at different times. Some of the parameters of this complex are closely related to the processes of skeletal maturation with com-

Table 8
Results of Study for the Six Groups.

Group	SNA mean	SNB mean	ANB mean	CA mean	SA mean exp.	SA act. mean	*d*	p
I	82.4[1]	78.1	4.3	12.2[2]	12.5	12.3	—0.2	< 0.10
II	84.2	76.9	7.3	12.2	12.4	12.2	—0.2	< 0.10
III	80.0	79.0	1.0	12.2	12.6	12.8	+0.2	> 0.50
IV	80.4	72.9	7.5	11.9	12.2	11.6	—0.6	< 0.01[3]
V	75.9	71.6	4.3	12.0	12.2	12.1	—0.1	> 0.50
VI	76.6	68.4	8.2	12.7	13.1	12.8	—0.3	< 0.10

1. Degrees
2. Years
3. Significantly different from 0.0.

mon physiological phenomena affecting both. In most children a similar pattern of skeletal maturation exists, both in terms of the shape of the curve, as well as its timing. Where this occurs, facial structures will be in a "normal" state of balance, other factors being equal. However, in some children deviations from this average maturation pattern will exist. Where such deviations exist, concomitant deviations from the usual facial growth patterns will also exist in those dimensions related to skeletal maturation.

The first two studies presented have demonstrated this by indicating differential relationships between certain growth measurements and skeletal maturation. The use of skeletal age as an indicator of growth rate significantly reduced the associated variation in those measurements more closely related. The second study further demonstrated that, in the mandible, spurts and lags in maturation activity were accompanied by similar spurts and lags in some aspects of growth. Study number three showed the clinical manifestations of these indications; a tendency for a particular kind of malocclusion was shown to exist where skeletal maturation was delayed.

The failure of Bambha and Van Natta (1959) to discover any such relationship can probably be attributed to two aspects of the design of their experiment. First, they utilized the Greulich and Pyle standards as skeletal age norms. It has been shown that average skeletal ages display regional variance (Gray and Lamons, 1959; Johnston, 1963) of such a nature that it becomes highly advisable to adjust standards of normality and the resulting assessments of individual children as "accelerated" or "delayed". Significant findings of a positive nature would not have emerged in the present study without such an adjustment.

Second, Bambha and Van Natta failed to make any kind of differentiation in types of malocclusion. The category "Class II", referring to a specific molar cusp relationship, is a composite; many facial and/or dental disharmonies can and do result in a Class II occlusion. The use of such a category without discrimination as to type, when complex biological phenomena are being investigated, can obscure potentially-significant information. Since a significant number of Class II malocclusions are purely dental in nature, their inclusion with those malocclusions related to skeletal imbalances results in such a heterogeneous group as to make significant findings difficult.

There is no implication to this study that skeletal age is the only factor in malocclusion; certainly the value of the coefficients of correlation and the nature of the variance reductions, while significant, left a significant component of variance to be explained by other factors. However, the knowledge of such relationships affords an extra depth to the orthodontist. The previously-demonstrated (Hewitt and Acheson, 1961) acceleration in maturation at puberty and the relationships shown in this paper make it desirable to insure that any tendency to "catch-up" at this time is fully realized. The patient who displays a small or retrusive mandible as well as a retarded skeletal age would perhaps benefit from watching to see if there would be any balancing out of the skeletal pattern as the adolescent spurt is entered.

Utilized in the above context, skeletal maturation becomes a factor which accounts for a significant portion of the variation in cephalofacial structure between children — variation, which may reach the clinically-important level of malocclusion. This is due to differential relationships between conventional methods of assessing skeletal maturation and certain aspects of growth. The realization of the above, and the incorporation of it into everyday practice, will permit a more accurate way to appraise the effects of growth progress, as it deviates from the ideal, in individual children.

Bibliography

Acheson, R. M. 1954 A method of assessing skeletal maturity from radiographs. *J. Anat.*, 88: 498-508.

Bambha, J. K. and P. A. Van Natta 1959 Longitudinal study of occlusion and tooth eruption in relation to skeletal maturation. *Amer. J. Orthod.*, 45: 847-855.

Bayley, N. 1943 Skeletal maturing in adolescence as a basis for determining percentage of completed growth. *Child Dev.*, 14: 1-46.

Bayley, N. and S. R. Pinneau 1952 Tables for predicting adult height from skeletal age: revised for use with the Greulich-Pyle hand standards. *J. Ped.* 40: 423-441.

Burstone, C. J. 1963 Processes of maturation and growth prediction. *Amer. J. Orthod.*, 49: 907-919.

Gray, S. and F. Lamons 1959 Skeletal development and tooth eruption in Atlanta. *Amer. J. Orthod.*, 45: 272-277.

Green, L. J. 1961 The interrelationships among height, weight and chronological, dental and skeletal ages. *Angle Orthod.*, 31: 189-193.

Greulich, W. W. and S. I. Pyle 1959 *Radiographic Atlas of Skeletal Development of the Hand and Wrist.* Second Edition. Stanford U. Press, Stanford.

Hellman, M. 1932 An introduction to the growth and development of the human face from infancy to adulthood. *Int. J. Orthod., Oral Surg. and Radiogr.*, 18: 777-798.

Hewitt, D. and R. M. Acheson 1961 Some aspects of skeletal development through adolescence. I. Variations in the rate and pattern of skeletal maturation at puberty. *Amer. J. Phys. Anth.*, n.s., 19: 321-331.

Hughes, B. O. 1958 Dental development and the child as a whole. *Amer. J. Orthod.*, 44: 565-574.

Ianantuoni, R. A. 1962 A study of the habit of finger and thumb sucking as an etiological factor in producing the Class II skeletal profile. *Orthodontic Cert. Thesis, U. of Penna.*

Johnston, F. E. 1963 Skeletal age and its prediction in Philadelphia children. *Human Biol.*, 30: 192-202.

Johnston, F. E. 1964 The relationship of certain growth variables to chronological and skeletal age. *Human Biol.*, in press.

Krogman, W. M. and V. Sassouni 1957 *Syllabus in Roentgenographic Cephalometry.* Growth Center Publications, Philadelphia.

Moss, M. L. and S. N. Greenberg 1956 Mesial movement of mandibular buccal dentition in treatment of Class II malocclusion. *N.Y. St. Dent. J.*, 32: 460-462.

Riedel, R. A. 1952 The relation of maxillary structures to cranium in malocclusion and in normal occlusion. *Angle Orthod.*, 22: 142-145.

Rose, G. J. 1960 A cross-sectional study of the relationship of facial areas with several body dimensions. *Angle Ortho.*, 30: 6-13.

Seide, L. J. 1959 The relationship of dentofacial growth and skeletal maturation to malocclusion. *Amer. J. Orthod.*, 45: 801-816.

Siegel, S. 1956 *Nonparametric Statistics for the Behavioral Sciences,* McGraw-Hill, New York.

Simmons, K. and W. W. Greulich 1943 Menarcheal age and the height, weight and skeletal age of girls age 7-17 years. *J. Ped.*, 22: 518-545.

Zung, I. P. 1964 Dental arch dimensions and dentofacial patterns in 47 children, age 7-10 years, with a neuromuscular deficiency (cerebral palsy), as contrasted with a random sample and a sample with Class I (normal) occlusion, both in the same age category. *MSc. (Dent.) Thesis, U. Penna.*