A Study of the Craniofacial Skeleton

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Human craniofacial growth studies have centered mainly on the sagittal plane. This is partly due to lateral cephalometric dimensions being less subject to distortion than those derived from the frontal plane, but also because craniofacial growth changes are more striking in the sagittal than frontal plane. The skull is a complex interrelated structure rather than a series of discrete bony units.[1-5] Even single bones, e.g., the maxilla, can be shown to comprise a number of interrelated regions.[6] Thus, a succession of changes occurs during growth in which the entire mosaic of the component bones is involved;[7] craniofacial growth is therefore the cumulative sum of the growth of all the separate bones of the neuro- and viscerocranium, each subject to varying degrees of genetic and environmental influence.[8,9] Yet despite the identification of many growth sites, the patterns of craniofacial growth remain controversial and often enigmatic. Indeed, the prediction of future growth changes cannot withstand critical scientific appraisal until craniofacial growth is better documented.

Growth of the facial skeleton after birth is more marked than that of the braincase, although the sizes of the postnatal increments vary both between different bones and between different dimensions of the same bone. The introduction of X-ray cephalometry,[10] in addition to meeting clinical demands for diagnostic and treatment planning criteria, has provided an invaluable tool for craniofacial analysis. In this regard, several standard cephalometric measurements have been adopted and various combinations of measurements have been described to form "analyses" of craniofacial morphology.[11-14] While facilitating a cursory analysis of craniofacial form, however, such "analyses" have yielded little data on the interaction between one part of the craniofacial skeleton and another, e.g., braincase and facial skeleton.

The relationship between maxillary and mandibular occlusion and skull morphology is particularly significant for orthodontic diagnosis and therapy. There is abundant evidence to suggest that occlusal variation is polygenic.[15] This means that occlusal relationships are controlled by many genes and various environmental influences, although extreme deviations are generally attributable to chromosomal or single gene defects.[16] The relationship between the maxillary and mandibular teeth is traditionally categorized by Angle's classification of malocclusion.[17] Such an arbitrary classification system is an attempt to impose discrete categories upon a continuously variable occlusion. Molar occlusion, however, undoubtedly reflects a complex interaction between various craniofacial components although the degree of interaction remains conjectural.

As a first step in the critical assessment of the craniofacial skeleton, this study was undertaken to compare accurate metrical descriptions of the craniofacial skeleton between 7 to 15 years of age and between various Angle occlusal categories.

MATERIALS AND METHODS

This cross-sectional growth study of the craniofacial profile spanned the period 7-15 years. A total of 100 male British Caucasoids were included in the study comprising equal samples in successive two-year intervals. The subjects were from a similar socioeconomic group and exhibited similar somatotypes. No subject was related to another and all were born and lived within the same 20 mile radius. Within each age group the subjects were assessed to be of similar dental age, as judged from intraoral radiographs and to possess a full complement of teeth. All subjects exhibited a "normal" anteroposterior first permanent molar relationship and a Class I skeletal relationship; no subject had received previous orthodontic treatment.

A further 150 male British Caucasoids, aged 10-12 years, were included in this study comprising equal samples of Angle's Classes I, II, Division 1 and II, Division 2, categorized by the method described by Beresford.[18] The skeletal categories of these patients were assessed according to the method outlined by Ballard[19] into skeletal Classes I and II. To simplify this study the subjects were selected so the occlusal categories coincided with the skeletal categories, i.e., Angle Class I with skeletal Class I and Angle Class II with skeletal Class II; no subject had received orthodontic therapy.

Lateral cephalographs were taken for each subject in an identical manner using a cephalostat. Subsequently, an accurate metrical craniofacial profile was obtained for each cephalograph using the technique described by Walker and Kowalski.[20] Thus each cephalograph was traced to provide a conventional pattern of the individual skull bones. One hundred and seventy-seven datum points were identified on each tracing. Each point was assigned a unique number which corresponded with all the conventional anthropometric datum points, e.g., nasion, menton, sella,[21] as well as a number of intermediate points, geometrically determined, to provide an adequate metrical definition of the shapes of the skull bones (Fig. 1). Subsequently, the "x" and "y" coordinates were recorded for each cephalograph in a set sequence using a strip-chart digitizer.

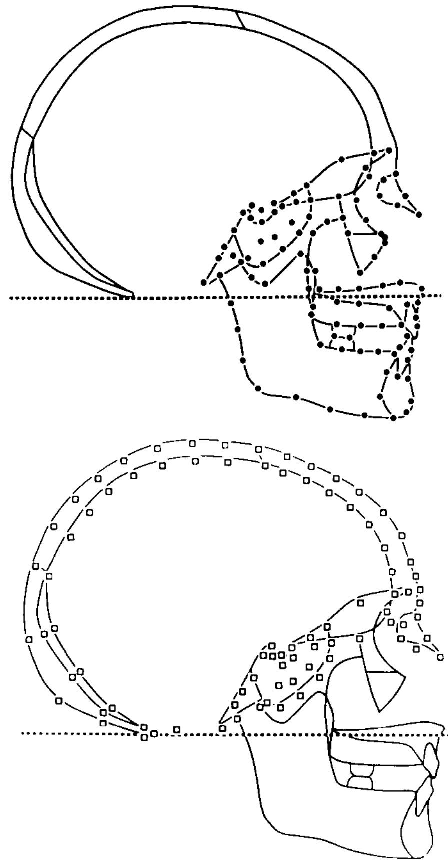

Fig. 1 Schematic outline of datum points defining craniofacial skeleton. Above, datum points defining facial skeleton. Below, datum points defining braincase. Note the cranial base is an integral part of both braincase and facial skeleton.

Despite precautions, the cephalographs were taken at varying elevations and orientations. Accordingly, they were transferred to a standard orientation using the technique of Cleall and Chebib.[22] This entailed the transformation of the datum points for each cephalograph to standardized coordinates based on a common set of axes predefined by a point of origin and a directional point common to all cephalographs. The axes for each cephalograph were shifted to the point of origin and rotated around it so the positive direction of the "x" axis passed through the directional point. The standardized coordinates in each cephalograph were subsequently subjected to analysis.

Using a technique previously described,[23] this study was based upon multivariate analysis of the standardized cephalometric coordinates derived from subjects in the various age groups. Canonical analysis was the multivariate technique selected to maximize the separation between the various age groups and to identify which craniofacial region exhibited the most marked changes during the period 7-15 years. Six analyses were performed between the various age groups using (a) all the coordinates of the craniofacial skeleton, (b) coordinates defining the facial skeleton, (c) coordinates defining the braincase, (d) coordinates defining the cranial base, (e) coordinates defining the maxilla and (f) coordinates defining the mandible.

In addition, the datum point coordinates defining (a) the whole craniofacial skeleton, (b) the braincase and (c) the facial skeleton were subjected to canonical analysis between the three occlusal categories.

The results of the analyses were examined by the standard method of plotting the position of the various age groups in relation to pairs of canonical axes. Inspection of the data showed that in each analysis only the first two canonical axes effected appreciable discrimination. Thus, the central point (centroid) for each age group was plotted for the first two canonical axes and this was circumscribed by a circle of radius 2.15 standard deviation units to include 90 percent of individuals. This clear, simplified procedure was adopted for all the analyses included in this study.

Results

The cross-sectional growth analyses (Table I) showed a similar pattern of age changes for the craniofacial skeleton as a whole with the facial skeleton. The growth curves tended to parallel one with another with the marked changes occurring between 7 and 9 years of age (Fig. 2). In no instance were the age-changes between successive age-groups statistically significant, although the changes between intervals of 4 or more years were significant. By contrast, the age-changes in the braincase were not marked during the period 7-15 years. These age changes were confirmed from the generalized distance (D^2) statistic (Table II) which provided an indication in terms of standard deviation units of the degree of separation between the means (centroids) of the various age groups. This table also shows that the maxilla, mandible and cranial base follow the growth pattern of the craniofacial skeleton and facial skeleton rather than that of the braincase.

An eigenvalue analysis, which was superimposed upon each canonical analysis, showed that no one datum point or group of datum points contributed more than others to the over-all age changes in all the various craniofacial regions included in this study. Moreover, when each analysis was repeated, but with the age range subdivided to 7-11 and 11-15 years, the cranial base contributed most to the age changes in the initial period and maxillary height in the latter age period. Generally, however, whereas one group of craniofacial datum points contributed most to the separation between successive age groups, another group contributed most between other age groups.

By contrast, there were marked contrasts of the craniofacial skeletons, facial skeletons and braincases between the three occlusal categories (Table III). In each of the three analyses a similar pattern of contrast between the

TABLE I

Coordinates of various age-groups for the first two canonical axes based upon the analysis of the craniofacial skeleton as a whole, the facial skeleton and the neurocranium.

	AGE GROUPS									
	7		9		11		13		15	
Region analyzed	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Whole craniofacial	12.7	2.8	14.2	4.3	14.7	5.9	15.2	8.8	15.4	12.9
Facial skeleton	9.8	2.9	11.4	3.8	12.5	5.7	13.4	8.2	14.1	11.7
Brain case	5.5	3.0	5.8	5.3	5.9	6.5	5.7	7.3	6.1	8.0

All coordinates in standard deviation units.

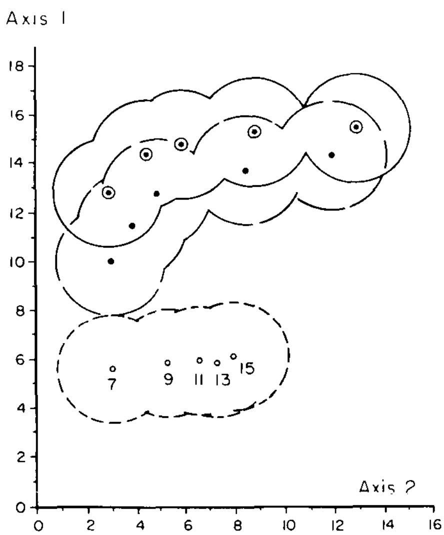

Fig. 2 Centroids and 90% confidence limits for the first two canonical axes, based upon analyses of various craniofacial regions between 7 and 15 years of age. ⦿ = facial skeleton, ⦿ = craniofacial skeleton; o = braincase.

occlusal categories emerged (Fig. 3), although the degree of separation was greater from analysis of the craniofacial skeleton as a whole compared with the facial skeleton or braincase (Table IV). Maxillary lengths and cranial base lengths, as judged from the eigenvalue analyses, contributed most to the discrimination between the three orthodontic categories.

Discussion

Both facial morphology and its location relative to the cranium as a whole have been established in part by a phylogenetic interaction of many factors including cerebral size, over-all brain configuration, cranial base adaptation to brain size, and body posture.[24] This study revealed that the two-dimensional sagittal growth patterns of the craniofacial and facial skeletons closely parallel one with another and are similar to

TABLE II

Squared generalized distance (D^2) between centroids (means) of different age-groups based on analysis of the craniofacial skeleton as a whole.

	AGE GROUPS			
Region Analyzed	7-9	9-11	11-13	13-15
Whole craniofacial skeleton	2.1	1.4	2.9	3.9
Facial skeleton	1.8	1.5	3.6	3.3
Brain case	2.2	1.4	0.9	0.7
Cranial base	1.2	1.4	2.3	2.1
Maxilla	1.4	1.5	2.5	2.6
Mandible	1.0	1.3	2.1	2.4

All generalized distances in standard deviation units.

TABLE III

Coordinates for first two canonical axes based upon analysis of the craniofacial skeleton in Angle's categories of occlusion.

Craniofacial skeleton analysed	Class I Axis 1	Class I Axis 2	Class II (1) Axis 1	Class II (1) Axis 2	Class II (2) Axis 1	Class II (2) Axis 2
Total craniofacial skeleton	19.6	2.8	22.4	14.7	6.0	7.9
Brain case	15.8	5.9	17.9	11.0	11.9	11.1
Facial skeleton	12.0	4.8	17.6	9.5	13.4	10.0

All coordinates in standard deviation units.

TABLE IV

Squared generalized distances (D^2) between centroids (means) of Angle's occlusal categories based upon analysis of the craniofacial skeleton.

Craniofacial skeleton analysed	Distances between centroids: Class I-II, (1)	Class I-II (2)	Class II, (1)-II, (2)
Craniofacial skeleton	12.2	15.8	16.7
Brain case	5.8	5.7	5.8
Facial skeleton	7.4	7.2	5.9

All squared generalized distances in standard deviation units.

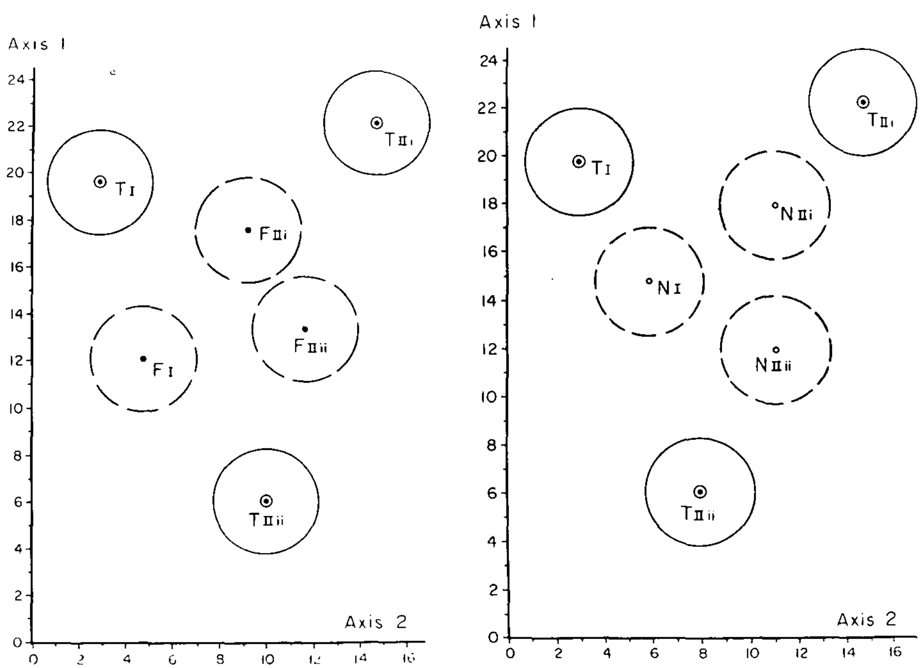

Fig. 3 Centroids and 90% confidence limits for the first two canonical axes, based upon analysis of various craniofacial regions between three occlusal categories. Left, analysis of whole craniofacial skeleton and facial skeleton. Right, analysis of whole craniofacial skeleton and braincase. I, IIi, IIii refer to occlusal categories; T = craniofacial skeleton as a whole; F = facial skeleton; N = braincase.

that of the cranial base. Such close correlation derived from cross-sectional growth data is indicative to the degree of association between one region of the skull and another.[4]

In man, the foramen magnum is located in the midventral part of the cranial base and the occipital lobes positioned in the endocranial fossae posterior to this foramen. Only the clivus (posterior portion of the cranial base) approximates the general vertical alignment of the vertebral column, whereas the anterior portion of the cranial base, associated with the frontal and prefrontal lobes, is horizontally aligned. The facial skeleton is adapted to this orientation and is essentially perpendicular to the vertical spinal axis. The cranial base flexure is therefore associated with an upright posture with the location of the facial skeleton pointing anteriorly.[25] The cranial base flexure is also a secondary skeletal adaptation to the shape of the brain itself, which also involves differential growth between the midventral brain axis and the cerebral hemispheres.[26] The facial skeleton is located within the cranial base flexure. Consequently, the orientation and location of the facial skeleton is, to a certain extent, dependent upon the growth and development of the brain and its extensions, e.g., orbits. This therefore indicates the close association between the neuro- and viscerocrania.

There are, however, two basic skull (brain) forms, brachycephalic and dolichocephalic, which are related to more closed (upright) and open (horizontal) types of cranial base flexure.[27] The more closed type of cranial base flexure leads to the nasomaxillary complex being located in a more posterior and superior relative location than the dolichocephalic type in which the nasomaxillary complex is located more anteriorly and inferiorly. Also the mandible is aligned in a forward and upward location in brachycephalics but downward and backward in dolichocephalics. Although this again confirms the close association between the neuro- and viscerocrania, the subjects were all dolichocephalic in skull form which in this study limited to a certain extent the variability of skull form.

It is erroneous, therefore, to regard the facial skeleton in isolation relative to the craniofacial skeleton as a whole or the cranial base.[28] Also, although both genetic[9,29] and environmental[30] factors affect craniofacal form, the relative weighting of these factors for each craniofacial bone has yet to be partitioned. Yet data from a twin study indicate that mandibular dimensions exhibit a greater degree of genetic variability than those of the remainder of the facial skeleton.[31] Even regarding the mandible in isolation, the width and length dimensions demonstrate a greater component of genetic variability than height.[31] Furthermore, facial growth is correlated with stature and skeletal maturation,[32] although the degree to which these two features are associated with genetic and environmental influences is controversial.

Many investigators contend that the incidence and severity of malocclusion increase with racial admixture and conclude that the occlusal relationships between the maxillary and mandibular dentitions are principally under genetic control.[33,34] There is, however, scant evidence to support this contention.[35] Epidemiological data indicate a relative high frequency of Angle's Class II and low frequency of Angle's Class III occlusions in European and North American Caucasoids,[36] with reverse frequencies relating to Alaskan Eskimos.[37] Moreover, Grew et al.[38] have reported a tendency toward Angle's Class II relationships in North American Indians increased in relation to the proportions of Caucasean ancestry. This suggests the presence of quantifiable genetic variations in the sagittal molar relationship and the possible existence of genes skewing the distribution of molar relationships toward distocclusion in populations of recent European derivation. By contrast, the increase in frequency of occlusal disharmony occurring within one generation after nontechnological societies are introduced to Western culture[39] suggests an important role for environmental factors.

Angle's categories of malocclusion are useful arbitrary divisions of a continuous variable. The results from this study, however, indicate that occlusal categories are not based simply upon the relationship of the first molars, but upon a complex interaction between many craniofacial structures. Occlusal relationships may vary depending upon pleiotrophic effects of one or more genes and/or environmental factors on several components of the craniofacial features.

Multivariate statistical techniques facilitate the simultaneous investigation of many craniofacial characteristics. Several factors limit the amount of data to be derived from this study, e.g., cross-sectional study, small sample sizes, hetero- rather than homogeneous samples. Nevertheless, the present study confirmed the association between the facial skeleton and the skull as a whole. Also accurate metrical data coupled with multivariate statistical analysis facilitate the investigation of the effect of any region of the craniofacial skeleton. Only by extending this type of enquiry based upon longitudinal data derived from large genetically homogeneous samples will it be possible to derive normative growth data to withstand critical scientific appraisal.

Summary

Multivariate analysis of craniofacial profiles demonstrated the complex interaction between the brain case and facial skeleton during growth and between various occlusal categories. Only by investigating craniofacial growth data still further will it be possible to establish normative standard growth patterns that can withstand critical scientific appraisal.

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