EIGHTEEN YEARS OF RESEARCH AT ILLINOIS (Cont.)

ALLAN G. BRODIE

(Continued from page 63)

Another study undertaken at this time was directed toward a determination of the behavior of areas during growth. All work in the department until this time had been restricted to linear dimensions, i.e., height of parts had been studied as had depth and both had been shown to be even and proportional. With a few exceptions they had not been plotted against each other. The availability of a planimeter made it possible to study the behavior during growth of such values as nasal area and oral area as viewed in norma lateralis. This work was done by Dr. Tirk whose thesis was entitled:

A Study of the Growth of the Head By Planimetric Method[1]

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The growth of the human head has been studied in a variety of ways. By far the greatest amount of work has witnessed the employment of the techniques and instruments of the physical anthropologist, that is, the sliding scale and calipers. These have been used on both dried skull and living material. More recently (1931), roentgenographic cephalometry has been the method of choice because of the opportunity it affords for longitudinal observation, that is, the study of the same individual throughout the entire growth period.

Hellman[10] [11] utilized anthropometric measurements in serial studies of living subjects. His findings indicated changes in facial proportions in the course of growth.

> "As the face grows larger the proportion of dimension in one plane changes its relation to that in another. Proportions also change when comparisons are made of different dimensions at different levels in different planes."

He also reported two periods of relative acceleration in the growth rate. One of these occurred during late infancy and was followed by a period of relative retardation. The second, more pronounced, occurred preceding puberty.

Davenport[7], who also used serial anthropometric techniques on living subjects, claimed changes in facial proportions and the appearance of an adolescent spurt.

Goldstein[9] employed anthropometric techniques on the living. His was a cross-sectional study and he reported changing facial proportions and adolescent spurting.

In discussing growth Todd [17] stated,

> "Developmental growth implies modification of proportion and constant readjustment of parts as well as local modifications."

Krogman, [13] measuring dried skulls, compared the growth of anthropoids to that of man. He, too, reported changes in facial proportion.

[1] Based on a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of Illinois, 1947.

These investigators employed methods which admittedly were not precise. Anthropometric measurement of the living with scales and calipers presents obvious obstacles to exact measurement and the use of dried skull material entails comparison of different individuals. The latter cannot take into consideration causes of death nor normal variations in morphology.

Broadbent[3] in 1931 outlined a technique for cephalometric roentgenography. By this method, which is widely enough known to require no description here, he was able to obtain exact serial material. Accurate longitudinal qualitative and quantitative information on the growth of the head became available for the first time and Broadbent[4] himself undertook long range investigations of large groups of growing children. His method consisted of analyzing growth by means of superpositioning of tracings of serial headplates and he made no reference to accelerations in growth rate.

The growth of the naso-respiratory area was studied by Rosenberger [16] from Broadbent's serial cephalometric roentgenograms. His work indicated changes in proportion in the area under consideration and two periods of relative growth acceleration.

Brodie,[5] [6] employing cephalometric films, engaged in a comprehensive study of the growth of the human head from the third month to the eighth year. In contrast to the investigators previously cited, he stated the most significant finding of his investigation to be the early establishment of a morphogenetic pattern, which once attained is constant throughout growth. He was the first to indicate definitely the constant proportionality of the face. The effects of birth molding and the growth of the head during the first three months of postnatal life was subsequently filled in by the work of Ortiz[14].

The present investigation was directed toward a determination of the behavior of areas during the growth period as contrasted to the usual method of employing linear measurements. Such a study should permit a statement of growth behavior in terms of two planes instead of one.

Method and Material

The areas under consideration were measured on successive tracings of the headplates by means of a Lasico Compensating Polar Planimeter No. 120 (Fig. 1). This is a precision instrument which measures areas enclosed by irregular as well as regular perimeters.

Longitudinal roentgenological series, obtained by the use of the Broadbent-Bolton cephalometer and techniques, supplied the material for this study. Tracings were made from the lateral roentgenograms and the areas to be studied were outlined. These were the nasal, oral, facial and cranial areas (Fig. 2). The areas were laid out as follows.

Nasal Area. Beginning at the fronto-nasal junction (nasion) the stylus of the planimeter was caused to follow the anterior margin of the nasal bones and the nasal notch of the maxilla to the anterior nasal spine. From here it was carried posteriorly along the palatal plane (drawn from the anterior nasal spine to the posterior nasal spine) to the intersection of this plane with the posterior border of the pterygoid process of the sphenoid, which it followed to the under surface of the body of this bone. The inferior contour of the sphenoid body was followed to the cribriform plate of the ethmoid and this was followed forward to nasion.

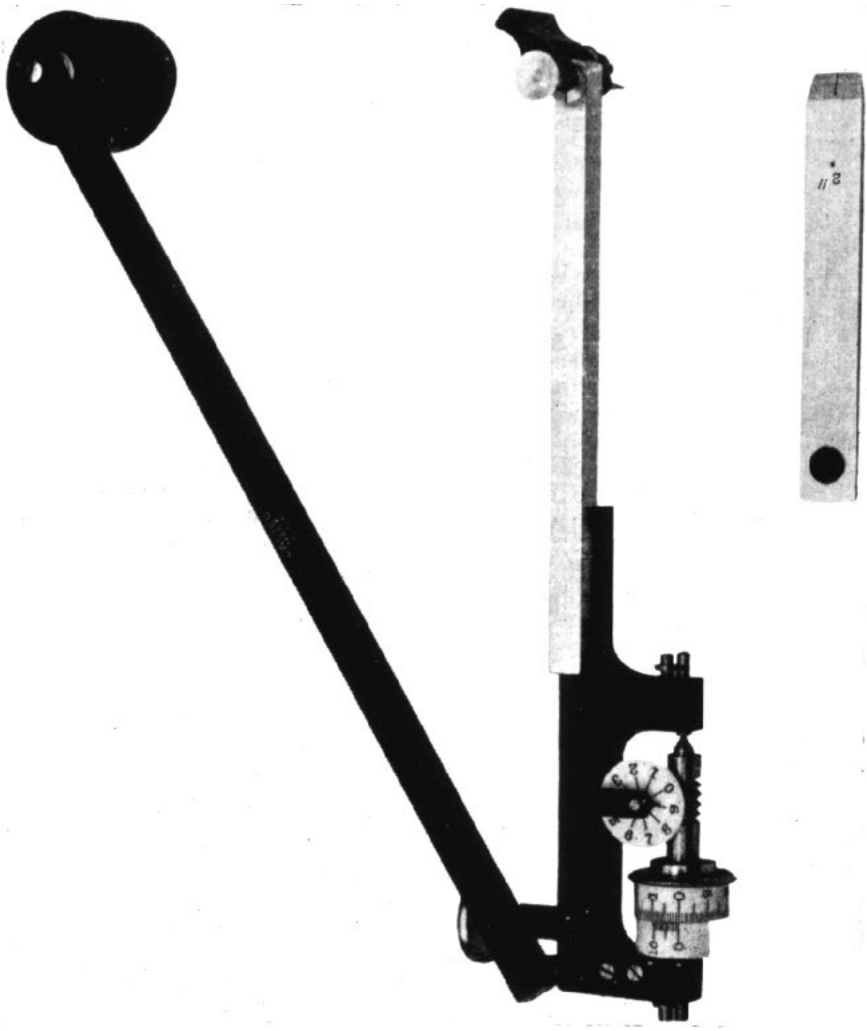

FIG. 1. Lasico Compensating Polar Planimeter. Reproduced with the permission of the Los Angeles Scientific Instrument Co.

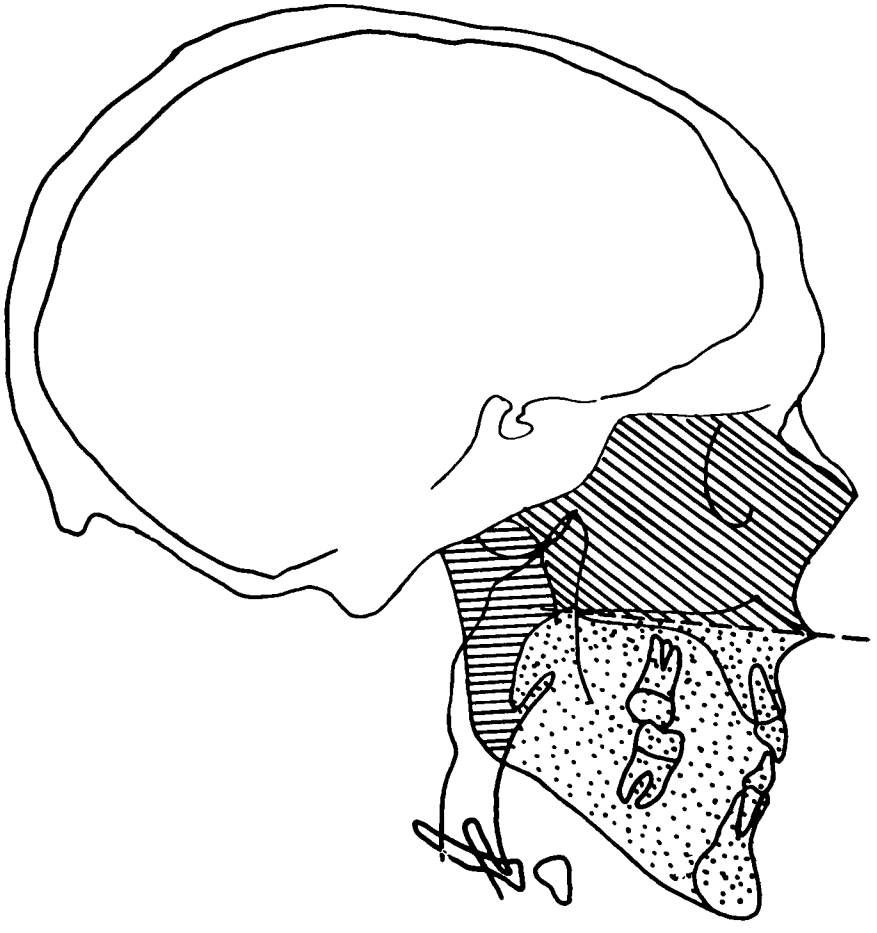

FIG. 2. Areas studied. Nasal area - diagonal lines; oral area - dotted; Cranial area - unshaded, bounded by outer table of brain case. Total facial - nasal and oral areas plus horizontally shaded area.

Oral Area. To enclose this area a start was made at the anterior nasal spine. The course traveled was the anterior outline of the maxilla, the labial surfaces of the maxillary and mandibular central incisors and the anterior and inferior contours of the mandible to its intersection with the dorsum of the tongue. The dorsum was followed to the superior surface of the uvula and soft palate and from here the palatal plane was once again used to the anterior nasal spine.

Facial Area. The line for this determination started at the fronto-nasal junction and followed in succession the anterior outlines of the nasal bones, the maxilla, the central incisors and the outline of the mandible to the point on the ramus where it intersected the lower border of the basilar part of the occipital bone. From here the course was forward along the contour of this bone and that of the underbody of the sphenoid. The superior border was the same as that used for the nasal area viz, cribriform plate to nasion.

Cranial Area. The cranial area was taken to be that enclosed by the outline of the outer table of the brain case. The inner table could not be used because of the lack of sharp definition. The facial and cranial areas were separated by the lower borders of the basilar part of the occipital and the body of the sphenoid plus the cribriform plate of the ethmoid. All areas were measured on each tracing by means of the planimeter.

It was necessary to compensate for enlargement when these area readings were taken directly from the tracings because growth increased the distance from the mid-saggital plane to the film surface (ML). For all practical purposes the X-rays may be assumed to emanate from a central point, the focal spot of the tube, and from here to expand in the nature of a funnel. It can be seen by referring to Figure 3, that the greater the ML distance, the greater the magnification. The readings obtained must, therefore, be adjusted accordingly.

Simple geometry and trigonometry will prove that the linear magnification is the same at any point on the film. To express it differently, a centimeter at the center of the film is magnified exactly the same amount as a centimeter at the periphery. Figure 3 demonstrates that, in order to prove the point just made, A′ must equal A″, if A represents two similar lengths at the mid-saggital plane. The mathematical proof is as follows:

$$\text{Tan } \angle A = \frac{\text{Opposite side}}{\text{Adjacent side}} = \frac{A}{5} = \frac{A'}{ML + 5}$$

$$A' = \frac{(ML + 5)A}{5}$$

$$\text{Tan } \angle AA' = \frac{2A}{5} = \frac{A' + A''}{ML + 5}$$

$$A'' = \frac{2A(ML + 5)}{5} - A'$$

$$\text{As } A' = \frac{(ML + 5)A}{5}$$

$$\text{Then } A'' = \frac{2A(ML + 5)}{5} - \frac{A(ML + 5)}{5}$$

$$A'' = \frac{(ML + 5)A}{5}$$

$$A'' = A'$$

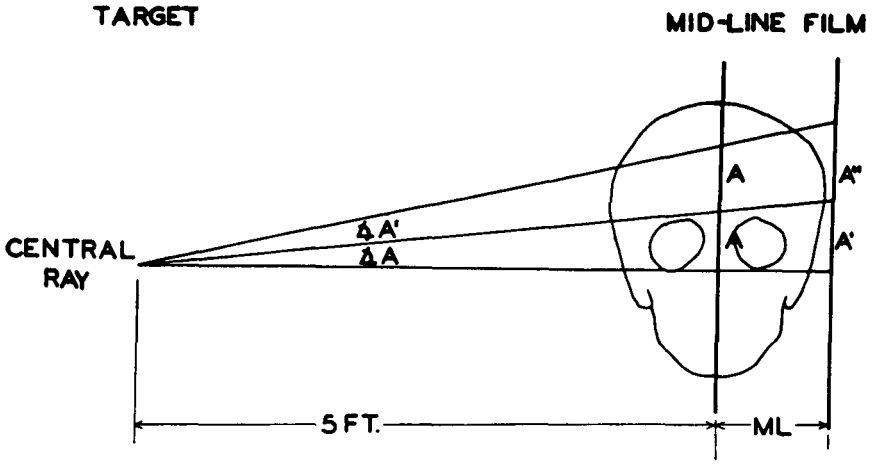

FIG. 3. Illustrating the mathematical proof for procedures used in correcting for x-ray divergence.

Since the linear magnification is a simple proportion (Adams[1]), a formula for area magnification can be worked out as follows:

$$\text{Magnified Area } (A') = \text{Linear magnification}^2 \times \text{Actual Area } (A)$$

$$A = \frac{A'}{\text{Magnification}^2}$$

$$\text{As Magnification} = \frac{\text{Target ML Distance} + \text{Film ML Distance}}{\text{Target ML Distance}} =$$

$$\frac{\text{ML} + 152.6 \text{ cm.}}{152.6 \text{ cm.}}$$

$$\text{Actual Area } (A) = \frac{\text{Magnified Area } (A')}{\frac{(\text{ML} + 152.6)^2}{(\quad 152.6 \quad)}}$$

All planimetric readings were corrected according to this formula, and the average area correction was found to be about 10% at 80 millimeters ML distance.

The serial roentgenographic material used in this study was obtained from the Bolton Foundation of the Department of Anatomy, Western Reserve University, Cleveland, Ohio, from the files of the Department of Orthodontia, University of Illinois, Chicago, Illinois, and from the records of the private practice of Dr. Allan G. Brodie. This series represented tracings made from films taken at three to six month intervals during the first year of life, annually for the following three years and biennially thereafter. In several instances this sequence was not followed because of blurred films and irregular intervals between roentgenograms. Fig. 4 illustrates the age range and the overlapping in these sixteen cases. The sixteen series were selected at random and the sample includes some Class II malocclusions (2173, 2130 and 2019) and a few orthodontically treated cases (DB, 2173, AR and HR).

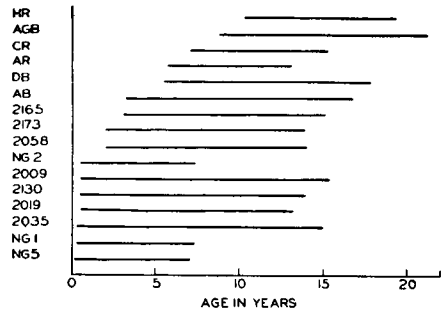

FIG. 4. Age range of cases.

Analysis of the growth of the cranio-facial areas under consideration was made from tabulations, derivations of mean values and from curves. Several cases were selected for detailed scrutiny because they represented typical curves for their age ranges.

FINDINGS

Case NG 5 (Fig. 5). Female, one month to seven years one month.

This child was premature and the first roentgenograms, taken at one month were assumed to represent conditions at birth.

The curves illustrate the growth of the cranial (C), facial (F), oral (O) and nasal (N) areas. The first impression gained is the smoothness of the curves. They are typical of growth gradients with increments gradually decreasing with age; each part growing at a progressively diminishing rate.

The three curves representing the facial areas and the total face show rapid growth during the first year, a leveling off at about a year and a half, and a subsequent maintenance of a more even intensity. The cranial curve shows early rapid growth with leveling off at about two to three years.

The three facial curves maintain their proportional relationships to one another. This consistent proportionality is indicated further by Table 1*, which shows the percentages of nasal and oral areas of the face and their ratios to one another.

This maintenance of facial proportion may be expressed differently. Table 1 shows that a facial area of 1.96 at one month of age increased to 8.20 at seven years and one month. This represents an increase of about four times. The oral area in the same period of time increased from 1.04 to 4.23, or about four times its original size. Nasal area also increased approximately four times its original size from .82 to 3.23. These areas, then, while all growing at different incremental rates, are growing at the same relative rates.

* Similar tables were prepared for each case but are not included in this report. All showed the same behavior.

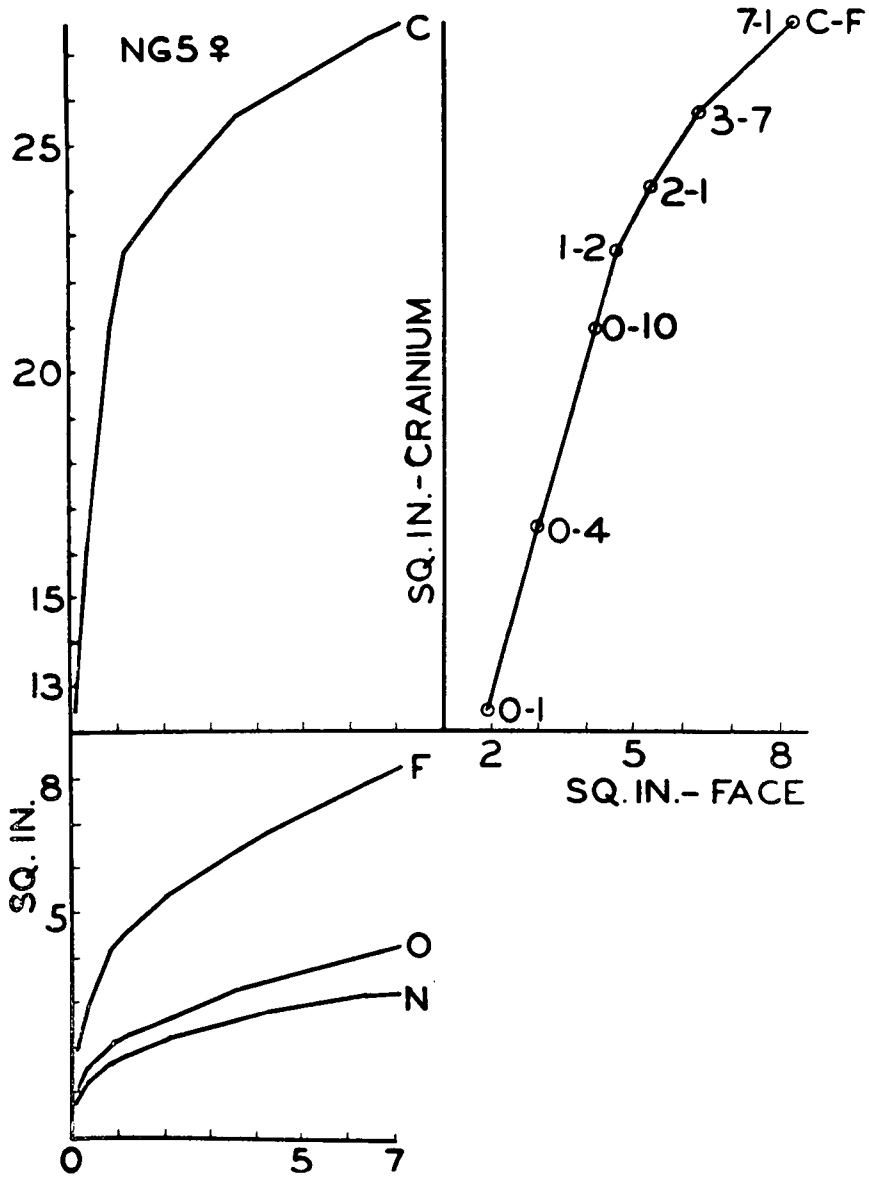

FIG. 5. Case NG5. The four left hand curves illustrate the growth of the cranial (C), facial (F), oral (O) and nasal (N) areas. The abcissa represents area in square inches and the ordinate age in years. The right hand curve (C-F) represents cranial growth plotted against facial growth with age indicated by numerals on the small circles.

TABLE 1

Case NG 5

Age in Years	*Nasal Area*	*Oral Area*	*Facial Area*	*Cranial Area*	*Nasal % of Face*	*Oral % of Face*	*Oral* Nasal*	*Cranium* Face*
0-1	.80	1.04	1.96	12.43	40.7	53.1	1.30	6.3
0-4	1.24	1.54	2.97	15.96	41.8	51.8	1.24	5.4
0-10	1.67	2.09	4.18	20.85	40.0	50.0	1.25	5.0
1-2	1.81	2.29	4.55	22.53	39.8	50.3	1.26	4.9
2-1	2.18	2.59	5.32	23.80	40.9	48.8	1.19	4.7
3-7	2.60	3.23	6.30	25.75	41.2	51.3	1.24	4.1
4-3	2.79	3.43	6.73		41.5	51.0	1.23	
6-4	3.13	4.00	7.87	27.15	39.8	50.8	1.28	3.5
7-1	3.23	4.23	8.20	27.50	39.5	51.7	1.31	3.4
Mean					40.6	51.0	1.26	

* Columns 8 and 9 are ratios. (8) is the oral area divided by the nasal area and (9) the cranial area divided by the facial area.

The nasal area varies only 1.3% from its average 40.8%. The oral area shows a similar behavior varying only slightly from its average of 51.0%. The slight variations on either side of the average values show no definite trend toward an increase or a decrease and, therefore, are considered to be due more to slight technical errors than to any differential in growth rates.

The ratio between oral and nasal areas shows the same consistency of proportion. There is no definite trend in its variations about the average, the extreme variation being .07.

Case 2173 (Fig. 6). Male, two years to fourteen years.

As the curves commence at two years they do not show the early rapid phase of growth. They do, however, show the progressively decreasing increments up to twelve years of age. After this point the three curves show increasing steepness indicating what is interpreted as an adolescent acceleration up to fourteen years where this series terminates. In this case, as in the preceding one the same consistency of proportion is observed.

Case AGB (Fig. 7). Male, eight years ten months to twenty-one years five months.

These curves show the steadily decreasing growth rate up to fourteen years. From fourteen to about sixteen there appears to be an acceleration in the growth rate with a leveling off of the curves thereafter. There is, however, a continuation of growth to twenty-one years in this case. No records of this case exist from sixteen years two months until twenty-one years, so that it cannot be ascertained whether growth progresses steadily to twenty-one or whether it levels off before this time. However, two other cases (DB and HR) show continuing growth up to eighteen years.

This case again shows the maintenance of facial proportion. The cranial curve is comparatively level over this period but, nevertheless, shows evidence of adolescent acceleration.

What appears to be an adolescent growth spurt has been observed in ten out of thirteen cases in the prepuberal and adolescent age range. Cases 2173 (Fig. 6), 2009 (Fig. 8), AGB (Fig. 7), DB (Fig. 9), 2035 (Fig. 10), HR (Fig. 11) show evidence of a definite acceleration, 2165 (Fig. 12), 2130 (Fig. 13), AR (Fig. 14) and CR (Fig. 15) gives indication of acceleration and AB (Fig. 16), 2058 (Fig. 17) and 2019 (Fig. 18) do not show any acceleration. Of those which fail to show acceleration, AB is a female, 2058 extended only as far as fourteen years and 2019 only to thirteen.

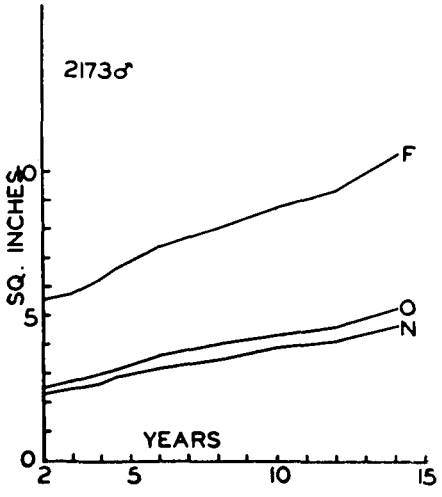

FIG. 6. Case 2173 (see text)

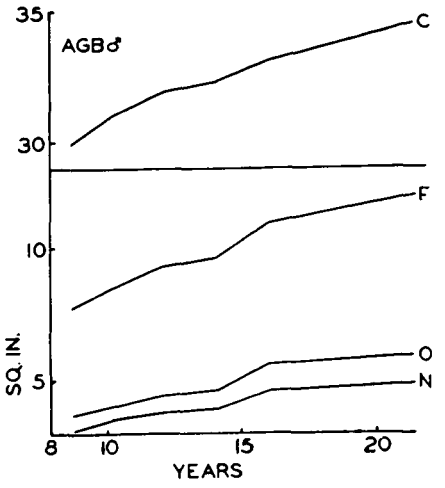

FIG. 7. Case AGB (see text)

This was a random sample and included some Class II malocclusions and some orthodontically treated cases. However, none of the cases in either of these categories showed any marked difference in the behavior of the growth curves.

The data were plotted (Fig. 21) in order to show their scatter. As the plotted points were not widely separated it was felt justifiable to establish mean curves for all the cases in the series. According mean curves (Fig. 22) were constructed for each age range and subsequently integrated.

The mean oral (O), nasal (N) and facial (F) curves show the same general features observed in the three individual cases discussed previously. They show early rapid growth which slows at about one to two years. Following this there is a period of gradually decreasing increments up to the early teens, when there is indication of an adolescent acceleration in rate. This appears in all four of the mean curves. Subsequent to the acceleration there is a period of levelling off until growth is completed. The curves, with the exception of the period of acceleration, are smooth, and even during acceleration maintain their relative proportions to each other.

The mean cranial curve (C) (Fig. 22) shows the same characteristics as those of the individual cases. There is early rapid rise, with a slowing down at two to three years; this is followed by a growth of more even intensity to about the twelfth year when an acceleration in rate is indicated. This is followed by a period of levelling off.

In addition to the area readings, percentages of oral and nasal areas of the face and their ratio to each other for each roentgenogram were calculated. They showed the same constant portionality and the slight variations from the individual means showed no definite trends toward an increase or a decrease.

Percentages of oral and nasal areas and their ratios were averaged for each case and then averaged for the series. Average nasal area percentage was found to be 41.1 with extremes at 37.0 and 43.0. Oral area was 49.1% with range of 1.38 to 1.09. These values indicated a fairly constant rela-

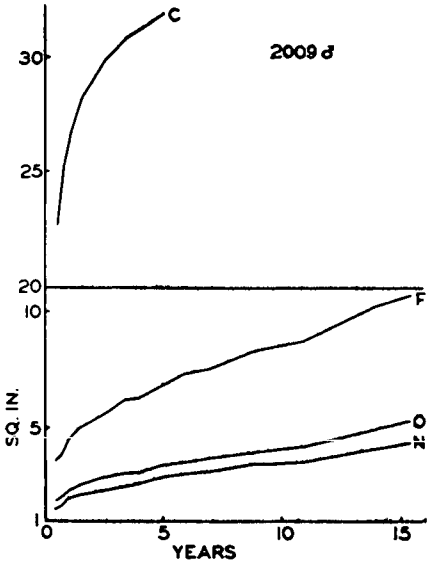

FIG. 8. Case 2009

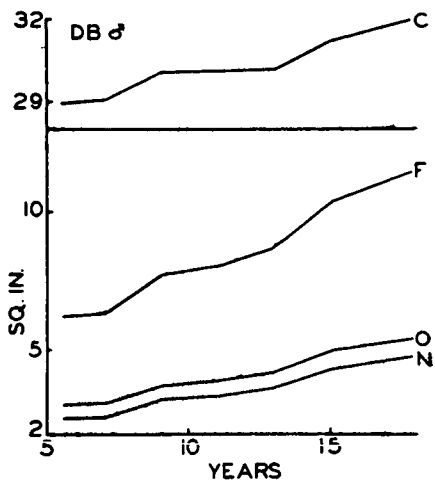

FIG. 9

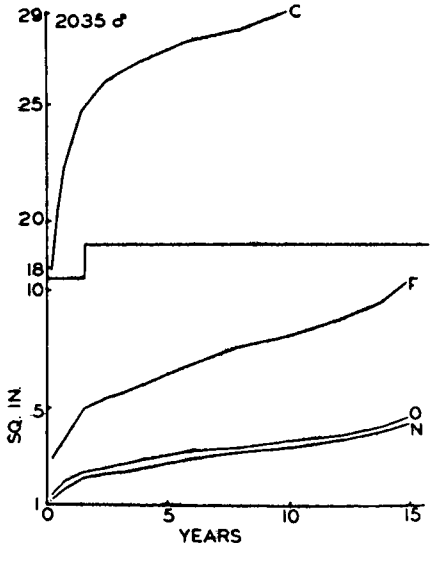

FIG. 10

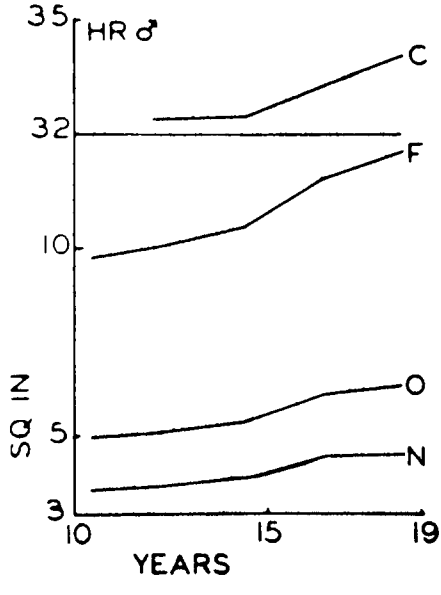

FIG. 11

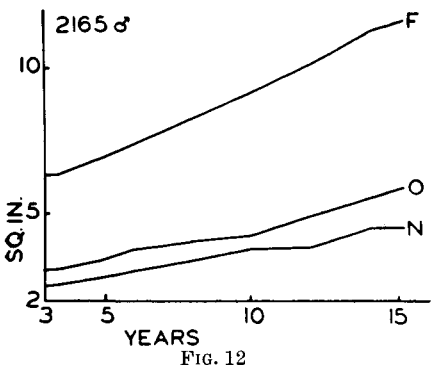

FIG. 12

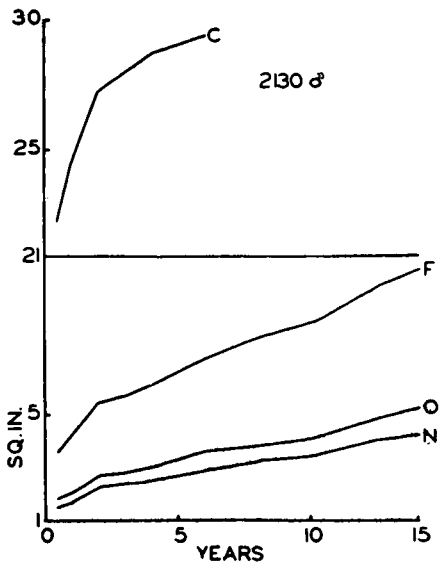

FIG. 13

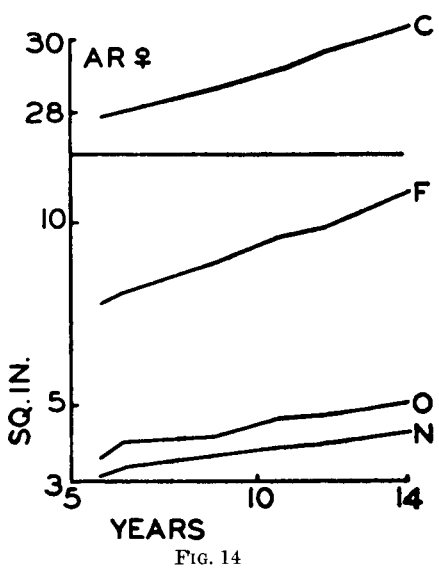

FIG. 14

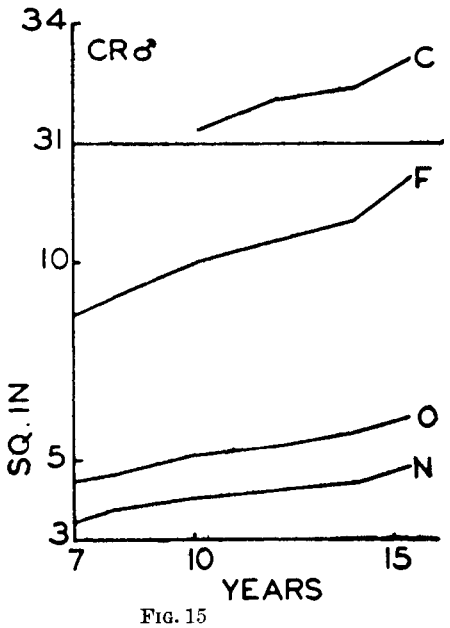

FIG. 15

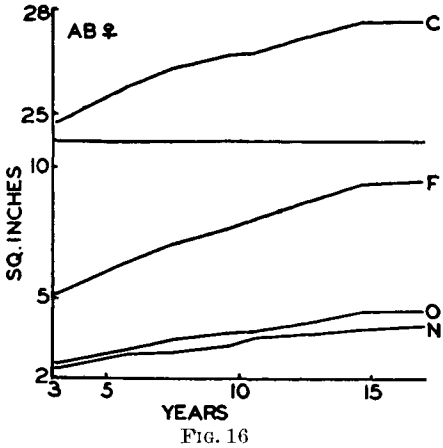

FIG. 16

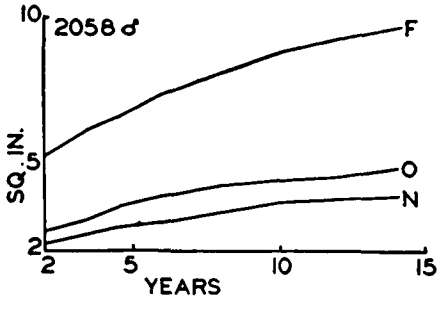

FIG. 17

tionship between the face and its two components. However, the size of the sample is too small to allow a statement relative to the general population.

Comparative rates of growth of face and cranium of Case NG 5 (Fig. 5) are indicated by the curve on the right of the figure where the two are plotted against each other. The abcissa represents facial area in square inches and the ordinate represents cranial area in square inches. Age is indicated by the small circles on the curve and by the adjacent numbers. This curve demonstrates graphically the early rapid growth of the cranium during the first year or two. The gradual slowing of this cranial rate and the comparative stability of the facial rate is indicated by the flattening of the curve at the two to three year period. Although the slope of the curve remains steep despite the slowing of cranial rate, it must be remembered that the cranium represents about three to four times the area of the face. Therefore, even a slower rate of cranial growth would result in a steeper curve. Calculation revealed a change in proportion between the two of 6.3 at one month (or birth) to 3.4 at seven years one month. This is a result of the relatively greater facial growth over a longer period of time.

The mean cranio-facial growth curve of the entire sample was plotted similarly to the preceding curve (Fig. 23). The increments of cranial growth were plotted against the facial increments. Age is indicated by the small circles on the curve. The curve showed clearly the gradually decreasing ratio between the two. As the cranial growth slows abruptly and the facial growth continues steadily the curve begins to flatten. The more rapid facial rate in the later stages is indicated by the approximate proportions of one to the other. Cranial area is shown to be six times that of the face at two months, five times at a year and a half, four times at six years, three times at fourteen years and two and one half times at eighteen years.

The difference between cranial and facial growth rates has been demonstrated in the previous paragraph. To illustrate the absence of a differential in intra-facial rates in contrast to cranio-facial rates the mean oral and nasal growth increments have been plotted against each other and against total facial growth increments (Fig. 24). It can be seen that plotting these facial increments against each other produces straight lines in contrast with the curves obtained by plotting face against cranium.

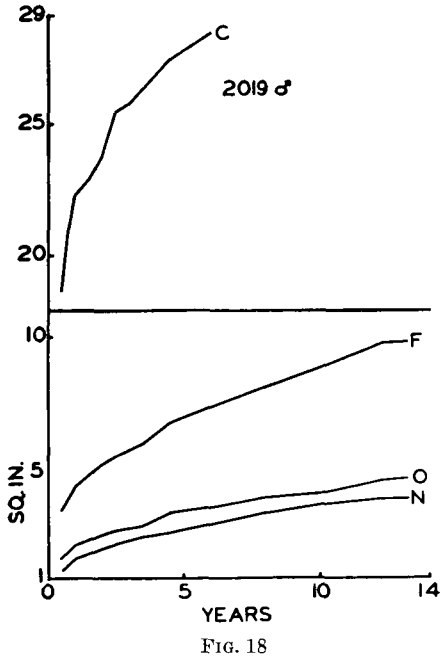

FIG. 18

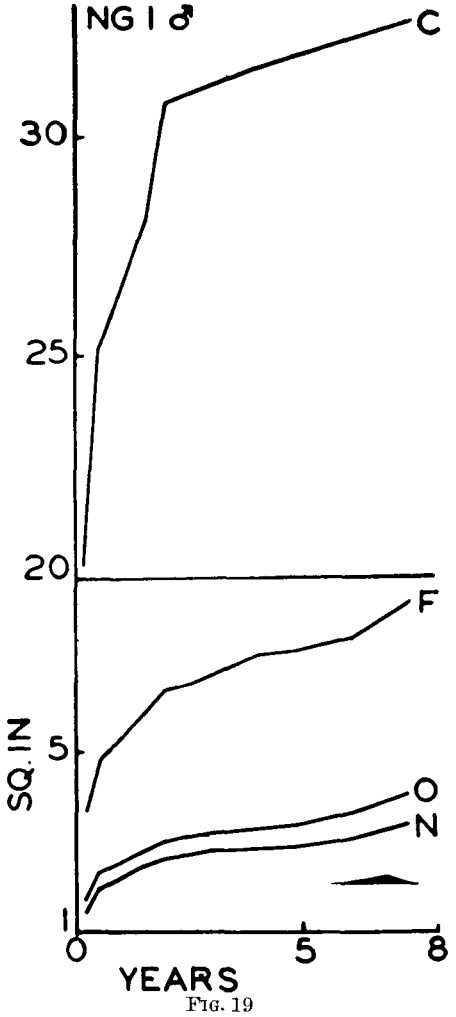

FIG. 19

DISCUSSION

This report represents an effort to study the relative growth of certain regions of the head on an area basis. A planimetric technique was employed on lateral cephalometric roentgenograms, in order to consider simultaneously increases in depth and height. Growth, of course, is a three dimensional or volume phenomenon.

The findings of this area study support to a great extent the reports of certain earlier investigators and particularly Brodie, who demonstrated the constancy of the parallelism of the planes of the face, the maintenance of angular relationships and the fact that anatomical points tend to travel on straight lines in the course of growth.

The results of this study indicate by a different method the early establishment of the facial pattern and the maintenance of the proportions of these areas to one another. The face, at least in norma lateralis, would seem to be growing as a unit with each of its parts contributing proportional increments.

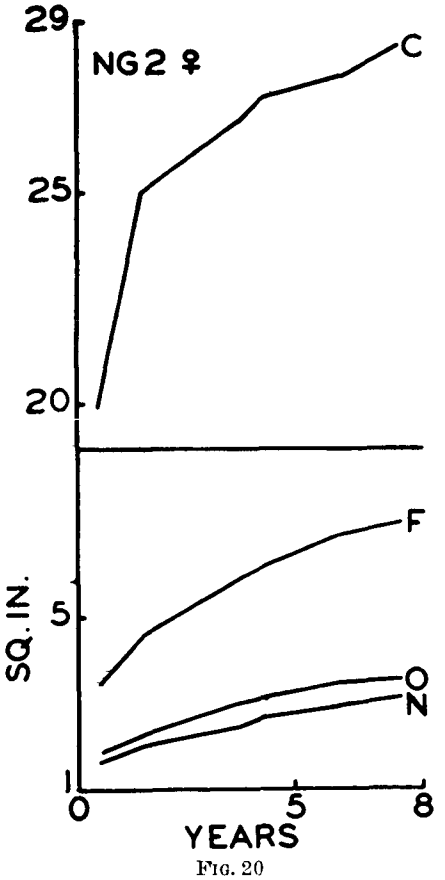

FIG. 20

The fact that the various components have attained marked differences in size by the third month would indicate either that there had been differential rates prior to this time or that some parts had commenced their growth before others. Brodie has stated the pattern, i.e., proportionality, is established by at least the third month and the work of Ortiz would indicate that it is prenatal.

In contrast with the proportional growth within the facial area, the comparative rates of the face and cranium show a differential, which results in the closing of the ratio between them of from 6.0 to 1, to 2.5 to 1.

The mean and individual cranial curves are indicative of the response of the brain case to the growth of the brain, presenting as they do a curve of the nural type. As the outer table has been used to outline the cranium, a certain amount of the growth indicated in later years may be attributed to additions to the outer table (sinuses, external occipital protuberance, etc.) as well as to slight further expansion of the brain case.

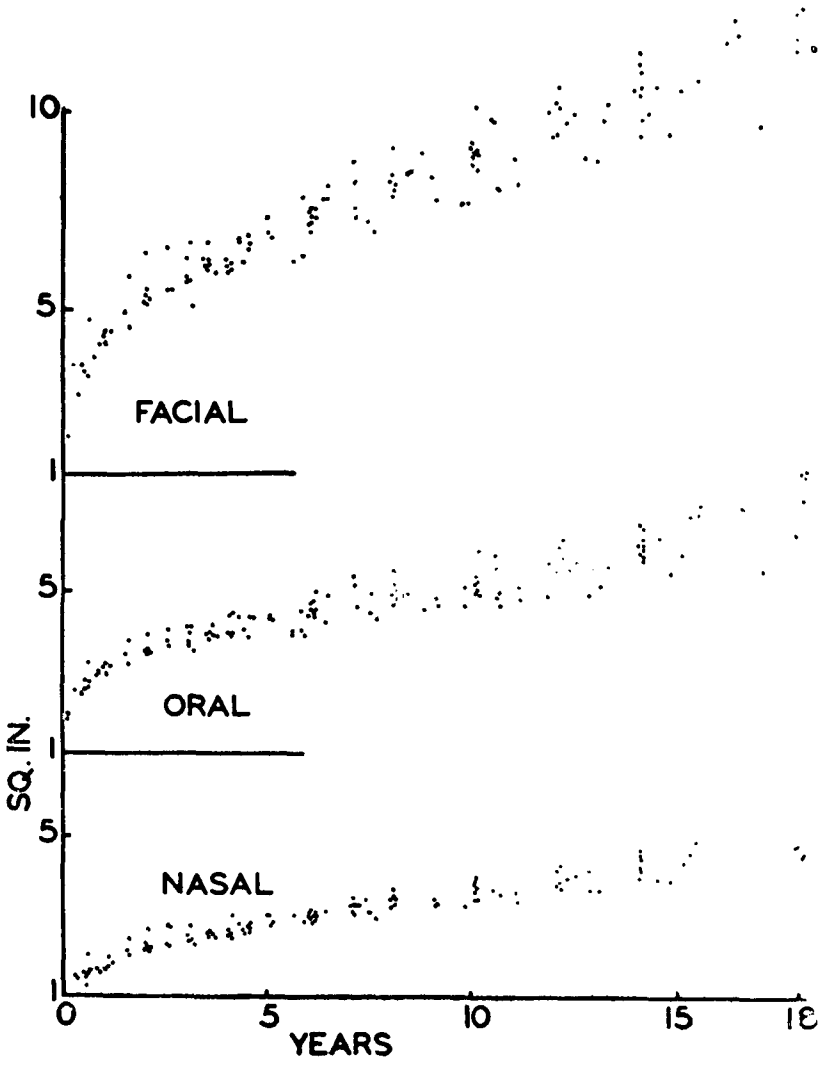

FIG. 21. Showing the scatter of the data.

All investigators working on samples involving teen ages have reported adolescent accelerations in the growth of the cranium and face (Goldstein, Davenport, Hellman, Rosenberger and Boas[2]. The present findings would also indicate the presence of this acceleration, but there is little definite evidence of an earlier acceleration as reported by Hellman and Rosenberger.

The growth curves indicate that up to and beyond the period of acceleration the rate decreases progressively and smoothly.

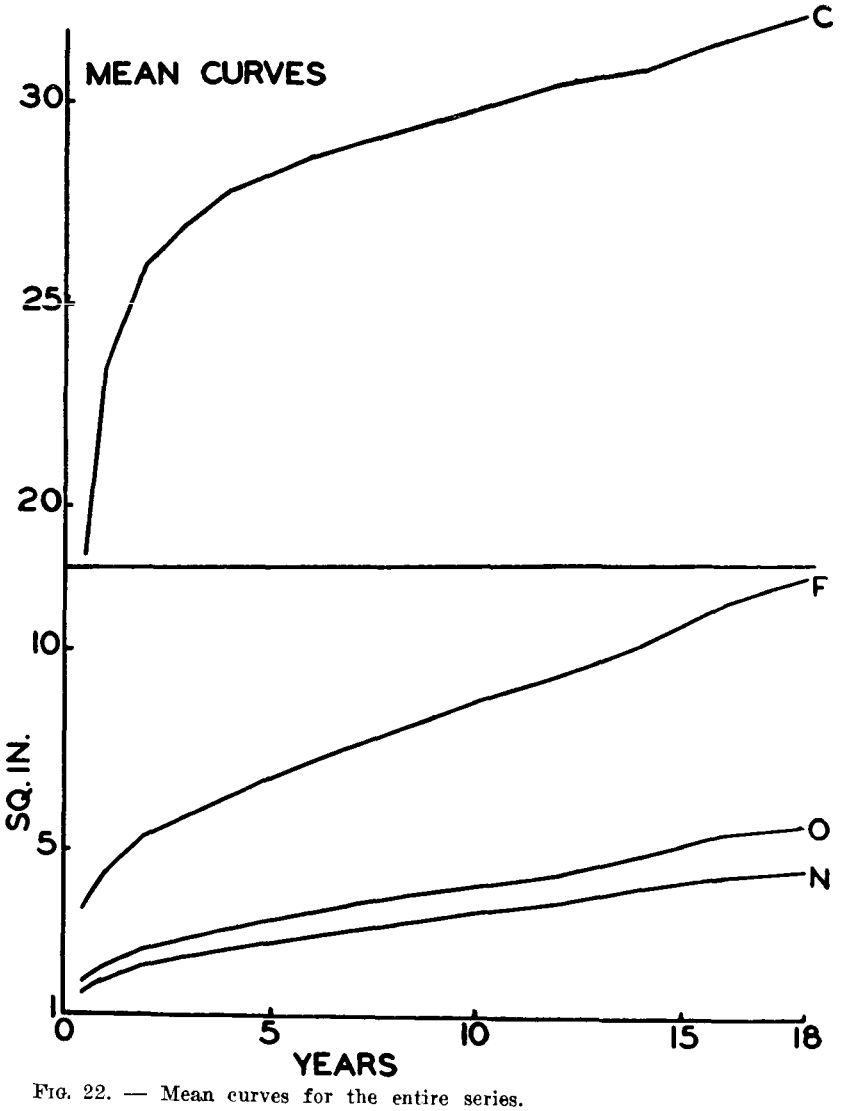

FIG. 22. — Mean curves for the entire series.

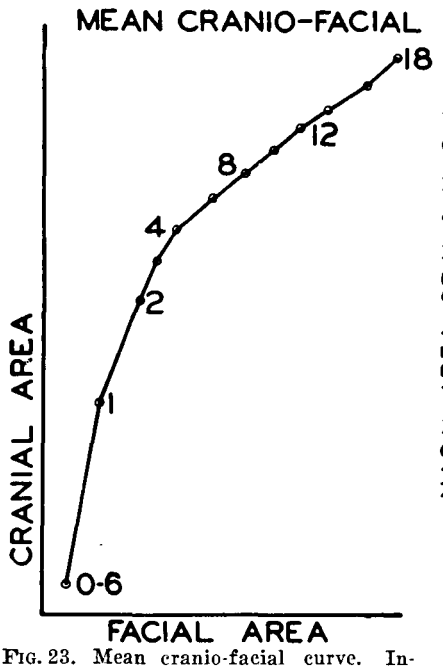

FIG. 23. Mean cranio-facial curve. Increments of cranial growth are plotted against increments of facial growth. Age in years is indicated by numbers next to the small circles on the curve.

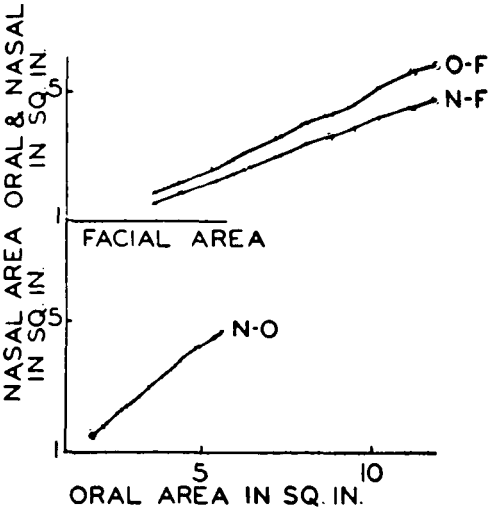

FIG. 24. Intra-facial areas plotted against each other and against the total facial area.
(N-O) Nasal against oral.
(N-F) Nasal against facial.
(O-F) Oral against facial.

SUMMARY AND CONCLUSIONS

1. A study has been conducted of sixteen individuals. Among these were three Class II malocclusions and four orthodontically treated cases. The records consisted of sixteen lateral roentgenographic series taken with the Broadbent-Bolton cephalometer. An appraisal was made of the growth of the nasal, oral, total facial and cranial areas by means of a polar planimeter.

2. The three facial areas exhibited consistent proportionality throughout the growth period, indicating the early delineation of a definite pattern of proportional growth.

3. In contrast with the proportional growth rates of the facial areas, comparative cranio-facial rates showed a differential. Plotting intra-facial growth increments against each other produced straight lines. Plotting cranial increments against facial increments produced curves. These curves were the results of early slowing of the cranial rate and the maintenance of a relatively more rapid facial rate over a longer period of time.

4. The evidence of this series indicated an adolescent acceleration in the growth rate of all areas studied. With the exception of these accelerations, however, growth was smooth and progressively diminishing in rate.

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