Growth behavior of the human bony facial profile as revealed by serial cephalometric roentgenology[1]

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Morphological growth studies in the past were limited by the lack of an accurate method which would permit the study of the same individual during the course of his growth period. Lack of such a method made it necessary for the early investigators to rely on skeletal material, largely of uncertain age.

STUDIES BASED ON SKULL MATERIAL

The physical anthropologists did most of the early work with skull material. Interested in racial characteristics and indices of proportion, they sought to quantify them by establishing planes, angles, and dimensions that were susceptible to accurate measurement. Associated with the development of planes were such names as Camper (1786), St. Hilaire (1795), Cloquet (1821), and Broca (1862).

Keith and Campion ('22) studied human facial growth from childhood to the adult, using immature and mature skulls and thirty-two living individuals. They attempted to determine the amount and sites of facial growth.

[1] Based on a thesis submitted as partial fulfillment of the requirements for the degree of Master of Science in Orthodontia in the Graduate College at the Chicago Professional Colleges of the University of Illinois, 1951.

Hellman ('22) investigated facial growth on a sample of 78 skulls of ancient American Indians. He classified the material on the stages of eruption, wear, and loss of teeth. This was a physiological time scale covering seven stages from early infancy to senility. He asserted that the mandible grew more rapidly in height and depth than did the upper face.

Gregory's work ('29) on the phylogenetic development of the face from early vertebrates to man was outstanding. Krogman ('30) studied facial growth changes in anthropoids and compared them with those in man.

Todd ('32) reported on a comparative head growth study to which ten investigators contributed. Besides Man, attention was devoted to hyenas, pigs, sheep, deer, baboons, orang-outangs, chimpanzees, and gorillas. Measurements were taken from the various skulls using the Western Reserve craniostat. This instrument permits a true orthographic projection of any chosen plane of the head. Todd concluded from this comparative study that contrary to the case in animals, there was no true prognathism in man. "In American negroes, the forward pace of growth in cranium and face is the same, but in whites, there is a tendency for facial extension to lag behind cranial."

Bjork ('50) studied the phylogenetic differences in prognathism from the lower apes, the man-like apes, the fossile ape-man, and recent homo by means of cephalometric roentgenology. He concluded that prognathism diminished phylogenetically because of a shortening of the jaws. Simultaneously with the reduction in prognathism there was also a deflection and shortening of the cranial base but the reduced prognathism did not arise from this concurrent process. He also noted that the shortening of the jaws affected the alveolar portions of the jaws more than it did the basal arches.

Anthropometric Studies on Living Individuals

Hellman ('35) made an important contribution through a study of 705 males and 988 females ranging from three to twenty-two years of age. A total of 45,711 measurements of external dimensions of the face were made by means of calipers. He concluded that, "the infant face is transformed into that of the adult by increases in size, by changes in proportion and by adjustment in position." He found that as the face grew, depth increased the most, height increased less, and width increased least of all. But the relative increases in height were greater in back (ramus height) than in front (total facial height), while the relative increases in width and depth were greater below (at the mandibular angle and in the body of the mandible.) than above (bizygomatic width and auriculo-nasion depth). The upper and lower face decreased in relative heights when compared with total face height. The difference was made up by the increase in the relative dimensions of dental height. With the increase in depth, the alveolar arches went forward more than the rest of the face. In the course of transformation, the face drifted gradually forward and changed in relative position to the cranium. Hellman noted that in this forward drift there were three recognizable trends: one was the average, or "normal", one diverged backward, and one forward.

Goldstein ('36) investigated the growth and development of the head and face, with particular attention to the latter. He took measurements on Jewish males at 2.5 to 3.5 years of age, and every other year thereafter until 20.5 to 21.5 years of age, with fifty individuals at each age. Height of the face was found to grow most and at the highest rate, with depth next in order in both respects, and width least. In height, the upper part of the face did not differ from the lower in relative growth. In depth, the lower portion of the face grew more rapidly than the upper. The alveolar region become more orthognathous with age whereas the face as a whole at the same time became more prognathous.

Davenport ('40) studied the postnatal development of the heads of several hundred children, utilizing serial material chiefly. He found that individual curves of head dimensions were strikingly variable. They increased to puberty, with adolescent accelerations. Chin height grew diversely in different individuals, probably because of the influence of special glandular activities. Other elements of facial height also varied with individual differences in tooth and sinus development.

Radiographic Studies on Living Individuals

Broadbent ('31) introduced a new technique of study utilizing a roentgenographic cephalometer. With this method, strictly comparable roentgenograms could be obtained in norma lateralis and norma frontalis of the head of the same individual during the course of his growth period. This outstanding contribution by Broadbent, marked the first development of an accurate technique for morphological growth studies on the living.

Broadbent ('37) reported on the normal developmental growth of the face employing the serial cephalometric technique which he had introduced. The findings were presented qualitatively in the form of superimposed tracings of roentgenograms of several stages from one month to adulthood. Broadbent concluded from his appraisal, "that growth of the face is not the complex erratic process that it seems to be by similar superpositioning of tracings from craniostatic drawings of skulls of dead children."

Brodie ('41) by means of serial cephalometric roentgenography studied the growth pattern of the human head on 21 males from three months to eight years of life. The findings were stated quantitatively with particular attention to the employment of angles and angular relations. The head was divided into several functional areas, i.e., brain case, nasal, dental, mandibular, and each was measured and studied as a separate entity. From the mean pattern of the sample, the most important finding was that the morphogenetic pattern of the head was established by the third month of postnatal life, or perhaps earlier, and that once attained it did not change. Growth of the various areas was found to be proportional and so integrated that various anatomical points traveled on a series of straight lines. After an early age, the nasal floor, the occlusal plane, and the lower border of the mandible were shown to retain stable angular relationships during growth. No change was found in the gonial angle. Another striking observation was the complete lack of any spurts of growth during the age span studied.

Bjork ('47) made a radiographic comparison of the facial prognathism of 322 twelve year old Swedish boys with that of 281 adult males. He found that prognathism increased somewhat during growth. Since no change in the shape of the cranial base was detected, the increase in prognathism was attributed to the altering relation between the cranial base and the jaw length. The increment in jaw length was almost proportional in both jaws. However, a slightly greater increase in mandibular as compared with maxillary prognathism was noted. This he believed could be attributed to the whole mandible's being displaced somewhat forward in relation to the upper jaw. This movement of corpus mandibulae was associated with the increasing height of the ramus, which during the same period grew at double the rate of increase of the facial height in front. The greater increase of mandibular as compared with maxillary prognathism served to straighten the facial profile as the individual grew older. Another factor which contributed to this effect was the slower rate of increase in alveolar as compared with basal prognathism.

The purpose of the present investigation was to study the resultants of the growth rates in various planes on the behavior of the facial profile. The author was interested in determining what changes in the form of the profile actually took place rather than the cause or sites of such growth changes. Attention was directed to general trends and to the range of variability. Finally, special attention was given to a correlation of individual growth behavior and the original facial type of the individual.

Methodology

The method for this study was based on serial cephalometric roentgenology. The technic for taking and tracing lateral headplates is well known It has been described in detail by Broadbent ('31) and Brodie ('41) and need not be elaborated upon at length.

In tracing bilateral anatomical structures, a line midway between the right and left sides was used. This, in effect, allowed the consideration of all structures as being in the mid-line, and also helped eliminate errors caused by improper positioning of the patient during exposure of the film.

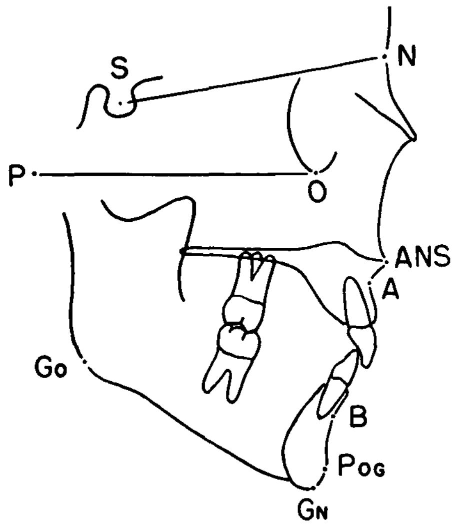
Distortion of the size of the image on the roentgenogram was a factor that also had to be accounted for when linear measurements were recorded. This was accomplished by utilizing correctional scales (Adams '40). The basic principle in the use of these scales is quite simple. If a leaded aluminum scale is attached at the midsagittal plane at the time a roentgenogram is taken with the Broadbent-Bolton cephalometer, its image appears on the finished film. It will be enlarged to the same extent as the midline structures of the head. The scale may then be cut from the film and used to take measurements of the roentgenogram. A series of scales were made to be used on different headplates depending on the distance of the film from the midsagittal plane. This distance, read from the calibrations incorporated in the Broadbent-Bolton cephalometer, is recorded at the time each headplate is taken.

Since this work was to concern itself with the growth of the bony facial profile, the following points were chosen to delineate the profile (Fig. 1):

N *Nasion.* The mid-point of the suture between frontal and nasal bones.

ANS *Anterior Nasal Spine.*

A *Subspinale.* The most posterior mid-line point on the premaxilla between the anterior nasal spine and prosthion.



Points Used In This Study
Figure 1

B *Supramentale.* The most posterior mid-line point on the mandible between infradentale and pogonion. (The above two points were used by Downs ('48) to indicate the anterior limits of the maxillary and mandibular denture bases.)

Pog *Pogonion.* The most anterior point in the mid-line of the mandibular symphysis.

Gn *Gnathion.* A point on the chin determined by bisecting the angle formed by the facial and mandibular planes. (The facial plane passes from nasion to pogonion. The mandibular plane is a line tangent to the lower border of the mandible posteriorly and the cross-section of the symphysis anteriorly.

Go *Gonion.* A point on the gonial angle determined by bisecting the angle formed between the mandibular plane and the plane representing the posterior border of the ramus.

In addition the following two planes were recorded:

SN *Sella Nasion.* A plane passing from the center of sella turcica to nasion.

FH *Frankfort Horizontal.* (cephalometric) A horizontal plane passing through right and left cephalometric porion (P.) and orbitale (O.) Cephalometric porion is the uppermost point on the soft tissue overlying the external auditory meatus. Orbitale is the lowest point on the inferior margin of the orbit).

SN was chosen as the plane for superpositioning and the successive tracings of each individual were registered at *nasion.* The angular relation between the FH plane and the SN plane was kept constant for each individual series, and represented the *mean* angle of all the SN-FH angles recorded from every tracing in the series. This is a modification of the use of the FH plane as it has been employed in the past by Broadbent ('37). Broadbent used the initial FH plane in each series and kept it constant for the remainder of each series. Because of the positional error in the FH plane that may be present from one headplate to the next, the use of a mean value was thought to be more reliable. Changes in the form of the profile in a horizontal or vertical direction were read from parallels with, or right angles, to the mean FH plane. For the purpose of illustration in the diagrams, a line was drawn through nasion parallel to the mean FH plane.

The following measurements were recorded from each tracing:

LINEAR READINGS	ANGULAR READINGS
N-ANS	S-N-ANS
N-A	S-N-A
N-B	S-N-B
N-Gn	S-N-Pog
Go-Gn	S-N-Gn
S-N	N-S-Gn
	SN-GoGn
	N-A-Gn
	FH-SN

Material

The material for this study consisted of 34 series of lateral cephalometric roentgenograms. Thirty-three were obtained from the files of the Bolton Study, Department of Anatomy, Western Reserve University through the generous permission of Dr. B. Holly Broadbent. One was obtained from the Department of Orthodontia, University of Illinois.

Only males were chosen and none had orthodontic treatment. No other criterion was used in an effort to obtain a random sampling of different facial types.

A total of 509 headplates were traced and there was an average of 15 in each series. The mean age span for the sample was from 4.4 to 17.1 years of age. However, not every series covered this age span. Twenty series included the 3 to 7 year age period. Thirty-two series covered the 7 to 12 year age interval. Twenty-seven series extended from 12 to a mean age of 18 years with a minimum age of 16 years.

Findings

The data obtained from this study were initially analyzed for three age intervals; namely, 3 to 7 years, 7 to 12 years, and 12 to 18 years. The angular readings for these three age periods were subjected to statistical appraisal. An effort was made to determine whether any changes in angular readings could be accounted for on the basis of chance alone. The probability of a difference being due to chance was determined from a calculation of Fisher's "t" statistic. Because of the serial nature of this experiment, "t" was computed by the following formula for a paired comparison experiment.

$$t = \bar{x} \frac{n(n-1)}{Sx^2}$$

where:
$\bar{x}$ = mean difference between pairs of observations
n = number of pairs of observations
Sx^2 = sum of squares of deviations from the mean difference

Fisher's "t" table was entered with (n-1) degrees of freedom. The five percent level was accepted as the level of significance. Thus, changes were accepted as significant when the probability (P) was less than .05.

The results of the statistical appraisal (Table I) revealed the following mean angular differences for the three age intervals.[2]

[2] The complete data upon which this study is based is available at the University of Illinois.

MEAN ANGULAR CHANGES

Angle	3 *to* 7 *years*	7 *to* 12 *years*	12 *to* 18 *years*
S-N-Gn	1.1	1.5	2.5
N-S-Gn	1.3	0.1*	—0.4*
S-N-ANS	0.2*	0.1*	1.7
S-N-A	—0.2*	0.1*	1.2
S-N-B	0.8	0.5	1.9
SN-GoGn	0.5*	—0.9	—2.2
N-A-Gn	2.6	2.7	2.4

*Not statistically significant

The significant mean changes in the form of the profile for these three age spans were illustrated by diagramming the angular readings and the corrected

TABLE 1

STATISTICAL DATA
3 TO 7 YEARS OF AGE
n = 20

Angle	Mean At 3 Years	Mean At 7 Years	Mean Difference	*S.D. of The Differences	t	P
S-N-Gn	74.4°	75.5	1.1	1.2	4.29	less than .01
N-S-Gn	65.3	66.6	1.3	0.9	6.42	less than .01
S-N-ANS	86.7	86.9	0.2	1.9	0.48	more than .5
S-N-A	81.11	80.95	—0.16	1.7	0.43	more than .5
S-N-B	75.54	76.38	0.84	1.5	2.44	less than .05
Sn-GoGn	32.9	33.4	0.5	1.9	1.15	more than .2
N.A.Gn	166.3	168.9	2.6	2.4	4.9	less than .01
7 TO 12 YEARS OF AGE n = 32						
S-N-Gn	75.7	77.2	1.5	1.3	6.62	less than .01
N-S-Gn	66.7	66.8	0.1	1.2	0.60	more than .5
S-N-ANS	87.2	87.3	0.1	1.5	0.37	more than .5
S-N-A	81.16	81.23	0.07	1.2	0.32	more than .5
S-N-B	76.7	77.2	0.5	1.3	2.32	less than .05
Sn-GoGn	33.2	32.3	—0.9	2.0	2.49	less than .02
N-A-Gn	169.0	171.7	2.7	2.4	6.48	less than .01
12 TO 18 YEARS OF AGE n = 27						
S-N-Gn	77.1	79.6	2.5	1.2	10.96	less than .01
N-S-Gn	67.0	66.6	—0.4	1.2	1.63	more than .1
S-N-ANS	86.8	88.5	1.7	1.4	6.14	less than .01
S-N-A	81.0	82.2	1.2	1.2	5.49	less than .01
S-N-B	77.2	79.1	1.9	1.2	8.21	less than .01
Sn-GoGn	32.3	30.1	—2.2	1.9	6.24	less than .01
N-A-Gn	171.8	174.2	2.4	2.8	4.46	less than .01

* Standard deviation of the differences between pairs of observations

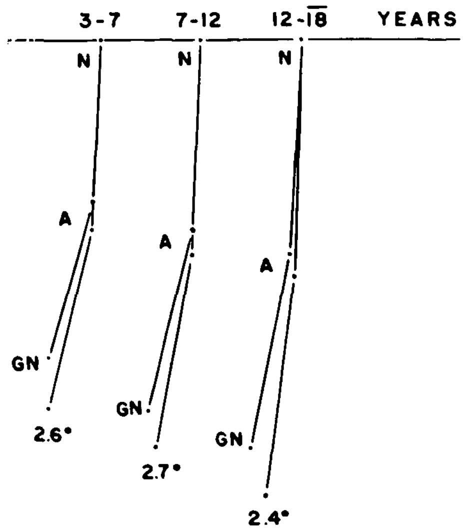
linear measurements of their sides. The resulting composite pictures are seen in Figure 2. Changes in the form of the profile in an anteroposterior direction, that is, parallel to the constant FH plane, are demonstrated.

The mean diagram for the 3 to 7 year age interval showed no significant change on the profile of points A, B, or Gn in an anteroposterior direction.

From 7 to 12 years the mean picture revealed a significant forward movemen of point Gn of 1.3 mm., but no significant change in either point A or in point B in an anteroposterior direction.

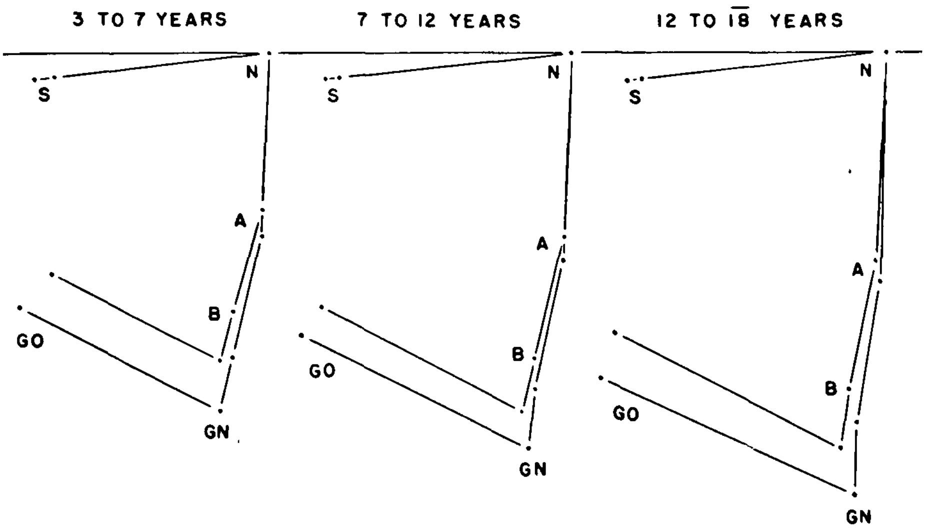
The mean diagram for the 12 to 18 year age interval showed significant forward movement of 1 mm. for point A, 2.2 mm. for point B, and 3.7 mm. for point Gn.

Changes in the convexity of the face were measured by changes in the angle N-A-Gn. An increase in the angle resulted in a decrease in the convexity of the face. This angle is comparable to the angle of convexity (N-A-Pog) of Downs ('48). Gnathion was substituted for pogonion because gnathion could be more exactly located as a point by employing an angular bisection of two planes. The continuous, mean change in the angle N-A-Gn for the three age spans was illustrated in Figure 3.

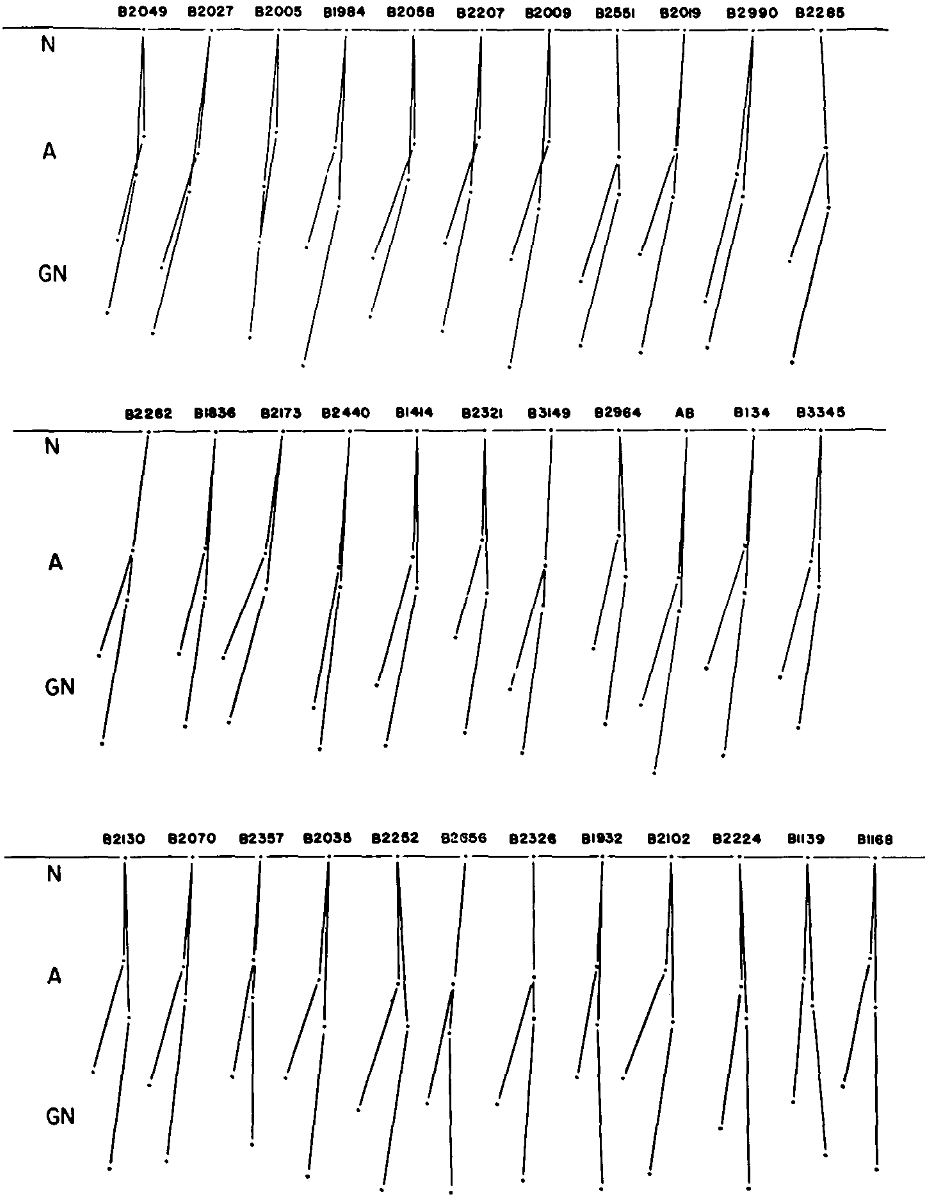


N - A - GN
Mean Changes
Figure 3

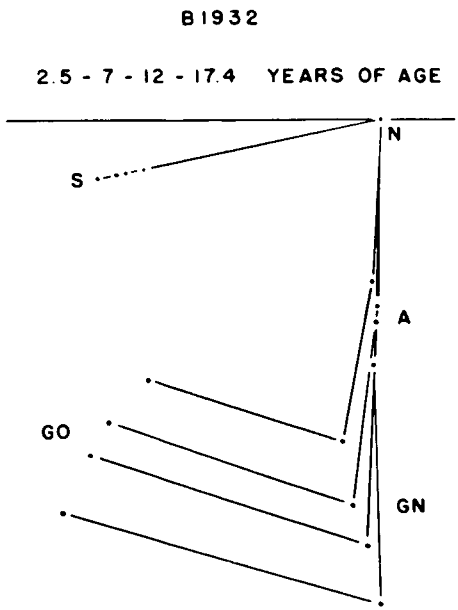
The findings discussed so far have been for three different age periods. Further consideration was given to each individual series, with special attention focused on the variability present.



MEAN PROFILE CHANGES
Figure 2



N - A - GN
Beginning and End of Each Series
The Series Are Arranged in Increasing Forward Movement of Gnathion on the Profile
Figure 4



Continuous Change of Gnathion
Figure 5

The amount of change at gnathion in an anteroposterior direction on the profile from the beginning and end of each individual series ranged from —3.75 mm. to +12.75 mm. (B2049 and B1168 — Fig. 4). Point A similarly ranged from —4.25 mm. to +3.25 mm. (B2005 and B2252 — Fig. 4). However, in only three series (B1984 — B2990 — B2049) did gnathion advance less in a forward direction on the profile than did point A. Even in these three cases the difference was never more than 2.25 mm. Series B2551 illustrates a case where neither point A or gnathion changed anteroposteriorly. In series B2656 point A went posteriorly and gnathion came forward.

In the majority of the series, point B advanced less in a forward direction than gnathion. In a few cases, the two points changed appreciably the same amount, but in no series did point B advance more than gnathion.

Most of the series showed a decrease in the angular relation between the lower border of the mandible and the SN plane. In a few series the angle did not change, but in only three series did an increase occur (B1984—B2027—B2049).

The convexity of the face nearly always decreased, but in a few cases the angle N-A-Gn did not change. However, in no series, from the beginning to the end, did the angle N-A-Gn decrease significantly, resulting in a more convex face. Series B2049 showed an increase of seven degrees in the angle N-A-Gn associated with 3.75 mm. posterior movement of gnathion on the profile. Series B2990 demonstrates a case where the angle did not change.

Even though the mean trend indicated changes in an anteroposterior direction after seven years of age, variation was seen. For example, series B1932 showed continuous change of gnathion from 2.5 to 17.4 years of age (Fig. 5)

The majority of cases did not vary in the direction of their changes in the individual series. If facial relationships were changing in one direction, these same relationships usually kept changing in the same direction in later years. Again, this was only the general trend and there was variation. Series B2102 illustrates changes in the same direction, while series B2070 demonstrates irregularity in the direction of changes. (Fig. 6).

Certain of the findings indicated that it would be worthwhile to ascertain whether there was any correlation between the amount of change in an anteroposterior direction and the original facial type of the individual. The mean findings had revealed that the greatest change in the form of the profile in an anteroposterior direction generally occurred after seven years of age and took place at gnathion. Therefore, the material chosen for this particular

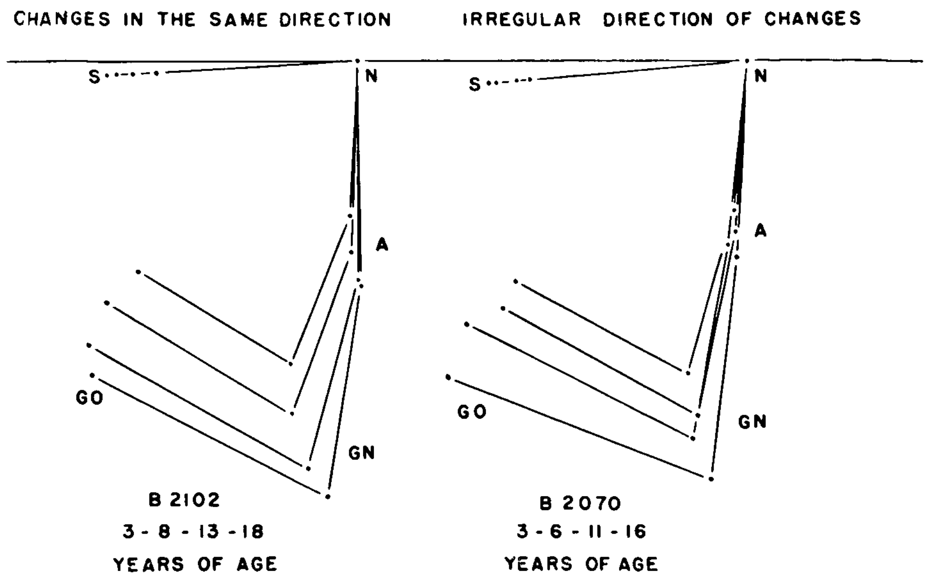


Figure 6

aspect of the problem included all the series which extended over the seven to seventeen year age interval. Twenty-five series covered this period. The amount of change at gnathion in an anteroposterior direction was then determined for each of the 25 series. Gnathion showed a statistically significant mean forward movement of 5.2 mm. The range was from —2.25 mm. to +12 mm. The original facial type of each individual at seven years of age was expressed by the following measurements of facial relationships:

1. Angle N-A-Gn
2. Angle S-N-Pog
3. Angle N-S-Pog
4. Angle SN-GoGn
5. Angle FH-NPog
6. Angle FH-SGn
7. Angle FH-GoGn
8. A-Gn

   This is the distance in millimeters between point A and gnathion measured in a direction parallel to the mean FH plane.
9. Gn-N

   This is the distance in millimeters between gnathion and nasion measured in a direction parallel to the mean FH plane.

Each of these nine readings at seven years of age was correlated statistically with the amount of change at gnathion in an anteroposterior direction from seven to seventeen years in every series. The results are seen in Table 2. These findings indicate that none of the coefficients of correlation was significant at the .05 level of probability.

Discussion

"Individual variation within the group is just as normal a characteristic of the phenomena as a whole as is the fact of the mean value" (Krogman '50 quoting Stevenson '34). Therefore, any analyses of growth changes must consider both mean trends and the degree of variability around such mean values. When these two factors were analyzed in this study, the following

TABLE 2
STATISTICAL DATA
7 TO 17 YEARS OF AGE
n = 25

Age Span 7 to 17	Mean Difference	Standard Deviation of The Differences	t	P
*Gn-Gn	5.2 mm.	3.6 mm.	7.19	less than .01

At 7 Years Of Age	Mean	Standard Deviation	Range		
N-A-Gn	169°	5.3°	162°.	—	179°
S-N-Pog	76.9°	2.5°	72.5°	—	82°
N-S-Pog	66.8°	2.3°	63°	—	72°
SN-GoGn	33.4°	3.2°	28°	—	40°
FH-NPog	82.70°	2.2°	78.2°	—	87.9°
FH-SGn	60.9°	2.3°	56.2°	—	65.3°
FH-GoGn	27.6°	3.3°	19.2°	—	32°
*A-Gn	11.6 mm.	3.3 mm.	5 mm.		16 mm.
*Gn-N	14.2 mm.	3.7 mm.	6.5 mm.		20.75 mm.

COEFFICIENTS OF CORRELATION

At 7 Years	7 to 17 Years	r	P
N-A-Gn	*Gn-Gn	.29	more than .05
S-N-Pog	Gn-Gn	.38	more than .05
N-S-Pog	Gn-Gn	—.28	more than .05
SN-GoGn	Gn-Gn	—.22	more than .05
FH-NPog	Gn-Gn	.22	more than .05
FH-SGn	Gn-Gn	—.08	more than .05
FH-GoGn	Gn-Gn	—.07	more than .05
*A-Gn	Gn-Gn	—.33	more than .05
*Gn-N	Gn-Gn	—.23	more than .05

* Distance between the two points measured in a direction parallel to the mean FH plane

observation on the profile appeared significant.

There was found a very distinct difference between the growth behavior of the maxilla and mandible in an anteroposterior direction. While the mandible tended to become more prognathic, the maxilla showed very little change. Point A was found to be more reliable than point ANS in studying maxillary growth changes in a horizontal direction, because the latter point may often lose its exact delineation through over exposure and processing of the roentgenogram. The increase in mandibular prognathism was in accord with the findings of Hellman ('27 and '35), Goldstein ('36) and Bjork ('47).

The mean tendency was for this increase in mandibular prognathism to occur after seven years of age. Thus, the mean picture up to seven years of age was similar to that shown by Brodie ('41).

Associated with the increase in mandibular prognathism was a decrease in the inclination of the lower border of the mandible — that is, it became more horizontal. Also, point B nearly always changed less than gnathion in a horizontal direction. This fact, together with the behavior of point A, substantiated the findings of Goldstein ('36), Bjork ('47) and Schaeffer ('49) that alveolar bone growth does not keep pace with skeletal bone growth.

Another observation was the change in the convexity of the face during all age periods. Except for a few series where it remained the same, the convexity of the face always decreased.

An interesting feature of this investigation was the correlation between growth changes in an anteroposterior direction and the original facial type of the individual. To the best of the author's knowledge, this represents the first time that such a correlation has been made. Facial type was used in lieu of occlusion of the teeth because of the fact that individuals may have similar facial types with different dental occlusions and vice versa.[3] The findings indicated that most of the cases in this study, regardless of differences in type, showed the same general tendencies in their growth behavior. In other words, the thought that has been expressed that a so-called "unesthetic" pattern becomes progressively more unesthetic with age was not borne out, i.e., the retrognathic face did not tend to become more retrognathic. It is important to note that this observation was made from a range of different facial types present in this sampling. To determine whether similar findings would be obtained with more extreme types will require further investigation.

[3] Ten of the thirty-four series showed Class II denture relationships.

Summary and Conclusions

An investigation on the growth behavior of the human bony facial profile has been described. Thirty-four males were studied quantitatively by means of serial cephalometric roentgenograms. The findings seem to warrant the following conclusions:

1. The mandible tended to become more prognathic in relation to the brain case during growth, but the maxilla showed very little change.
2. The increase in mandibular prognathism generally occurred after seven years of age.
3. There was a decrease in the inclination of the lower border of the mandible associated with the increase in mandibular prognathism.
4. Alveolar bone growth did not keep pace with the growth of its skeletal base in a horizontal direction.
5. The convexity of the face nearly always decreased.
6. There was found no correlation between the original facial type at seven years of age and the growth changes at gnathion from seven to seventeen years of age. The majority of the cases in this study, regardless of type, showed the same general tendencies in their growth behtvior.

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