The Behavior Of The Cranial Base And Its Components As Revealed By Serial Cephalometric Roentgenograms *

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Although the significance of the cranial base has long been recognized by biological workers, it is difficult to find it exactly defined. All agree on its importance as indicated by its preformation in cartilage and by its location in the zone which marks the union of head and body. Modifications in its form and proportions are held to be the reflection of adaptive changes that have occurred between the brain case and the face as well as those between the head and body.

As in all fields of study, investigation has been limited in this one by a lack of more suitable methodology. Thus the greatest proportion of observations have been made on animals and on human skull material. These have yielded important information on the phylogeny of the head. The study of the ontogeny of the human skull has been restricted, of necessity, to methods of averaging groups of skulls of varying ages. Such methods are questionable because of the paucity of skull material available in the younger age ranges, and by the large range of variation encountered.

With the advent of cephalometric roentgenology in 1931 it became possible to follow the growth of the living individual; both cross-sectional and longitudinal or serial studies have been conducted by this method. However, this method also has certain limitations imposed by the necessity of holding the head in a rather precise position. This is accomplished by means of ear-posts which, together with the arms that support them, are almost radiopaque and hence obscure certain landmarks. The variation of the anatomical relation of the petrous portion of the temporal bone to the spheno-occipital junction likewise makes the delineation of the latter difficult in many cases. For these reasons investigators sought landmarks more readily discernible in the lateral head x-ray. Thus Broadbent and Brodie have employed the Bolton point* as the posterior terminal landmark of the cranial base and Bjork, for a similar reason has advanced Articulare**. Recent modifications of technique have revealed the possibility of locating Basion on even those lateral headplates taken previously. Since this is a midline point it was selected for use in the present study.

An understanding of the growth of the cranial base has come to assume great importance in orthodontics. All recent investigations in this field have indicated that the successful treatment of malocclusions depends largely on the growth of the patient. At first the orthodontist restricted his attention to the dental area alone. He gradually came to realize that the facial skeleton to which the teeth and alveolar proces-

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* Deepest point on the curvature behind the occipital condyles.

** Point of intersection between the shadows cast by the dorsal contour of condylar process of the mandible and the temporal bone.

ses are appended were in turn related intimately to the cranial base, the upper face to its anterior part, and the mandible to the posterior part. Furthermore, any change which occurred between anterior and posterior cranial base, as for example, changes in the angle between them, could have striking results in the relations of facial parts.

For the purposes of the present study the cranial base in the midsagittal plane is made up of the basilar part of the occipital bone, beginning at Basion, the body of the sphenoid, the cribriform plate of the ethmoid and the thickness of the frontal bone. The connective tissue sutures between these bones would permit active growth and adjustment in an antero-posterior direction, contributing to the development of the skull as well as to the forward projection of the face.

The incremental growth of the cranial base in man and the relative growth of its parts were studied in this investigation. Serial data for each individual were available over the period from 3-18 years. Measurements were made from cephalometric roentgenograms obtained from the Bolton Study at Western Reserve University. In general, the findings revealed that the incremental growth curve of the whole cranial base resembled the neural type of Scammon ('36), and that the relative contribution of any one part, once established, did not change significantly within one individual over the period studied. This constancy in proportion was also observed to be a characteristic of the entire group studied.

II. Review of Literature

From both phylogenetic and ontogenetic views, the development of the cranial base has been associated with neural structures, that is, the sense organs and the brain. The contour and relation of the anterior and posterior parts have been thought to be adaptations to postural influence.

Bolk ('22) felt that the cranial base was adapted to the size and form of the brain. In his "Fetalization Theory" he concluded that "man represents a fetus of a primate which has become mature." He considered the foramen magnum and the occipital condyles to be the more fixed points of the cranial capsule. He pointed out that the more central position of the cranial base in man was the position characteristic for the preservation of the fetal state. He believed that the foramen magnum and the occipital condyles were shifted backwards in postnatal life. Dabelow ('31), one of Bolk's students, also held that the configuration and alteration of the cranial base was due to growth of the brain alone.

Weidenreich ('24) believed that the size of the brain was responsible to some degree for the form of the cranial base. However, he believed that its configuration was primarily associated with the attainment of the upright gait. He was particularly interested in the change of the cranial base angle which occurs in phylogeny. Weidenreich showed that this "deflection angle" decreased from fish to man and was correlated with upright posture and the diminution of the face as the size of the brain increased and overrode it. He further correlated this deflection to the manner in which the skull met the vertebral column. He believed that by means of the kyphotic downward bend of the skull base, there came about a curving and shortening of the visceral axis of the brain and a shifting of the nose-mouth region into a space underneath this arch.

A number of investigators have made cross-sectional studies of the change in the cranial base with age. Virchow (from Weidenrich '24) designated the angle formed by the clivus and the planum ethmoidale as the "saddle angle" and claimed that this angle decreased from birth to puberty.

In 1937 Broadbent, the inventor of cephalometric roentgenography, advanced certain planes of the heads as more suitable for the purpose of serial comparison of the same and different individuals than those commonly in use at that time. All of these lay in the zone of junction between cranium and face. Among others he mentioned S-N (center of sella turcica to fronto-nasal junction) and S-B (center of sella turcica to the Bolton point). Since that time, the angle N-S-B has been employed by a number of workers as the cranial base angle. Bjork ('47) studied the facial profiles of Swedish boys and conscripts. He measured the angle formed between nasion, sella turcica and articulare and found that this angle opened in some individuals and closed in others. He related this angle to the degree of prognathism in the face. Brodie ('51) measured the angle formed by Bolton point, sella turcica and nasion and found that this angle remained unchanged in half of his cases and increased or decreased in the rest.

Keith and Campion ('22) were among the first to attempt to study, quantitatively, the growth of the cranial base in the human skull. Using a series of skulls, they suggested that the increase in size can occur at three sutures, namely, the spheno-occipital, the spheno-ethmoidal and the fronto-nasal. They found that the amount of growth at the fronto-ethmoidal suture was very restricted. The spheno-ethmoidal junction was concerned not only with the growth of the face but also with the increase of the nasal cavities and particularly the brain case. Growth at the spheno-occipital junction permitted enlargement of the brain and backward movement of the auditory meatus. In this way space was provided for the growth of the mandible and pharynx.

Brodie (41), using cephalometric roentgenology for serial studies, measured the cranial base by dividing it into four parts. These divisions were: (1) center of sella turcica to the Bolton point, (2) center of sella turcica to the spheno-occipital junction, (3) center of sella turcica to nasion and (4) center of sella turcica to the spheno-ethmoidal junction. From these measurements he concluded that the anterior cranial base at three months was longer than the posterior portion but that postnatal growth of the two was almost equal. After 1½ years the growth of the various segments comprising the cranial base seemed to maintain the same relative rates of increase. Neither the absolute size nor the relative proportions of the cranial base were shown to have any influence on type.

III. Material

Serial cephalometric roentgenograms of twelve normal white females and eighteen normal white males were selected from the files of the Bolten Study of Western Reserve University. The range of age for this study was from 3 to 18 years. Of these thirty cases, five had undergone some type of orthodontic treatment. There was an average of eleven roentgenograms for each child. In all cases the occlusion was considered to be Class I (Angle). Cephalometric roentgenograms of five newborn children were selected from the files of the Orthodontic Department, University of Illinois to supply supplementary data on the very early postnatal period.

IV. Method

The roentgenographic technique was that described by Broadbent ('31). This insured consistency of results because the relation between the tube, subject and film were standardized, permitting superposition of later film tracings with a satisfactory degree of accuracy (Adams '40).

Dried skulls were marked with lead at all points that were to be studied in order to determine the accuracy with which they could be located in an x-ray of the living. Measurements between points were made directly on the skull and subsequently on the film for comparison.

The cranial base was demarcated by the midsagittal landmarks, basion, sella turcica, and nasion*. Since the cranial base has a curved configuration and these points can be shown to lie on the arc of a circle, the cranial base could be described by certain angular measurements involving these points. The necessary constructions are shown in Fig. 1. An arc of a circle was constructed to pass through basion, sella turcica, and nasion. (Three points not in a straight line determine a circle.) The perpendicular bisectors of the chords between basion and sella turcica and sella turcica and nasion were extended until they intersected. This located the center of the circle. The radius was then measured as the distance between this point and the center of sella turcica and the circle was scribed from this center. The length of the cranial base in the midsagittal plane was expressed, as a first approximation, by the length of the arc from basion to nasion. (The error in most cases was considerably less than 10 percent when compared to the actual cranial base measurement.) This was calculated by measuring the angle θ subtended by the arc Ba-S-Na. The length of the arc was expressed by the equation $L = \frac{\theta \pi r}{180}$.

After erecting lines from the center of the circle through basion, sella turcica, the spheno-occipital junction, the spheno-ethmoidal junction, and nasion, the center angles were measured between any two radii (Fig. 1). Although SO and SE did not always lie precisely on the arc, they were always in close approximation to it. In those cases the lines were projected to the arc. Each angle was compared to the total cranial base angle Ba-C-Na and a ratio was computed by dividing the angle of any one arc by the total cranial base angle.

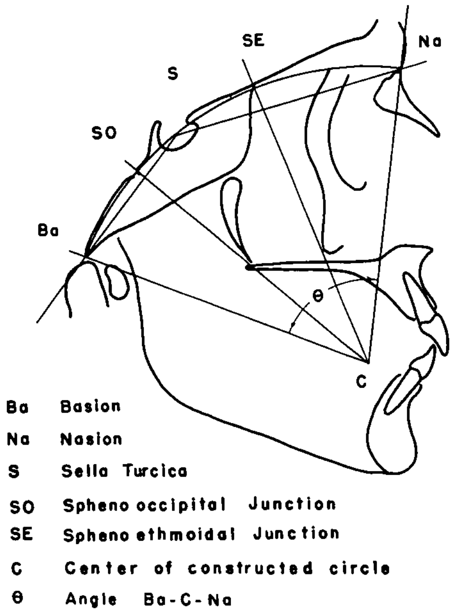

Fig. 1. Landmarks used in this study showing construction of arc through points Ba, S, and Na with projections through SO and SE.

From this data, it was possible to determine the incremental growth of the cranial base in each individual over a period of 12-15 years and the relationships among the components of the cranial base could be determined.

The angle Ba-S-Na was measured in all roentgenograms.

V. Findings

Relative Growth (Tables I-III, VI, Figs. 2-5)

For all individuals the mean value of the ratio of the posterior part of the cranial base from basion to the spheno-occipital junction (Ba-So) to the total

* It has been necessary to accept Nasion as the terminal because of the impossibility of locating the fronto-ethmoidal junction in the x-ray image.

cranial base was 25 percent with a standard deviation of ±1.7. The range was from 21% — 28%. The mean value of the ratio of the middle portion contributed by the body of the sphenoid (SO-SE) to the total cranial base was 37 percent, with a standard deviation of ±2.1%. The range was from 35% — 44%. The ratio of the anterior portion (SE-Na) to the total cranial base had a mean value of 38% with a standard deviation of ±1.8 and a range from 34% — 43%.

For each individual the ratio of each component of the cranial base to the whole remained virtually unchanged from 4-18 years. When the tracings of Case B 3361 are superposed on the center of the constructed circle, it can be seen that the lines representing the cranial base at three different ages are concentric (Fig. 6). It should also be noted that the proportions of the components remain relatively unchanged.

Cranial Base Angle (Table IV, Fig. 7)

The angle Ba-S-Na had a mean value of 130° with a range of 120°-143°. Twelve cases showed no change from 4 years to 18 years, while 18 cases did show some change. In only 5 of these did the angle change more than 4 degrees. The largest change was a decrease of 9 degrees. The changes in the deflection angle in this small group were not associated with any change in the relative length of the cranial base com-

TABLE I

Case No.	*Age* 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Av.
B3149				21	23	22	24	23	24	24	22	21	25	25	23	24		24			23
B3019			23	24		25	23	22	24	24	24	25	23		23						23
B 114			23	23	23	25	25	23	24	25	25	26	26								24
B 107				22	21	22	23	22	22	23	22	22	23	23	23						22
B2301				22	23	24	24	24	24	24	24	24		25							24
B2441		24	24	24	24	24	24	24	24	24	25		25								24
B 130				24	24	25	25	26	26	26	27	26	26	26	25						25
B 118				27	27	27	27	28	27	27	26	26									27
B 129			23	23	23	24	24	24		25	24				25	24					24
B 112	27	27	27	27	27	27	27	27	28	27	27										27
B 124				26	27	25	25	26	26	26	27	27	26	26							26
B 126			25	25	25	25	25	26	25	25	25	26	25	26							25
B 136			28	28	27	27	27	27		27	28	27	27								27
B3533		21	21	21	21	21	23	23		24			24								22
B2107			24	25	25	25	25	25	25	25	25	25	25								25
B2798				24	26	25	25	25	26	26	28	27	27								26
B2817			22		22	22	23	24	23	24	25	26	23	24		24					24
B2816		23	22		23	23	23	25	24	25	25		25								24
B2739				25	24	24	24	24	24	23	23		24								24
B2067		26	26	26	26	27	28	28	28	27	28	27	27								27
B2375			25	26	27	27	27	27	27	27	27	26	26								26
B2186			24		25	26	26	25		24	25	26	26	26							25
B2333		22	22	23	23	23	24	24	23	23	24	24		23							23
B3361			23	25	25	23	25	24	24	24	24	24	24								24
B2656			26	27	27	25	26	25	26	25	25	26	23	28	27	27					26
B2601		24	24	24	24	26	23	26	27	26	26	27									25
B2357		24		25	24		24	24	25	24		24	25	23	25						24
B2440						26	26	27	27	26	26	25	24	24	25	26					26
B2305	22	21	23	22	22	22	22	22	24	24	23	24	24	23							23
B1984	23	23		25	25	25	24	26	23	22	25										24
Min.	22	21	21	21	21	21	22	22	22	22	22	22	23	23	23	24					
Max.	27	27	28	27	27	27	28	28	28	27	28	27	28	28	27	27					
Mean	24	23	24	24	24	25	25	25	25	25	25	25	25	25	25	25					

PERCENTAGE OF BA-SO TO THE TOTAL CRANIAL BASE ponents.

Incremental Growth (Table V, Figs. 8, 9)

The linear measurement of the cranial base was calculated for each case at annual intervals, using the equation $L = \frac{\theta \pi r}{180}$.

From these calculations, curves of the annual incremental growth were plotted for each individual and a mean curve was plotted for the entire group.

Each curve showed accelerated growth until around five years of age. From 5-13 years, there was a period of deceleration with noticeable decrease in rate for a 2-3 year period between the ages of 9-13 years. After 13 years of age there was a slight acceleration in the rate of growth which diminished with the approach of early maturity (20 years). It was not possible in most instances to establish a difference between males and females with respect to time of the deceleration.

A mean terminal length for the cranial base of approximately 130 mm was estimated by inspection and extrapolation of the mean incremental curve. An approximate measurement of the cranial base at birth was also estimated from a small group of records of newborn children. From this data the percentage of total growth attained at each age was calculated and plotted.*

* Since the data used to calculate this curve are incomplete at both ends of the series, these results may be subject to minor modifications.

TABLE II

Case No.	*Age* 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Av.
B3149				41	39	40	39	38	37	37	38	39	36		35	35		35		41	37
B3019			37	37	40	37	37	38	38	36	37	35	37		37						37
B 114			38	38	37	36	37	38	37	37	36	36	36								37
B 107				44	44	43	43	43	43	42	43	43	42	42	42						43
B2301				40	39	38	37	38	38	38	38	36		35							38
B2441		43	42	41	40	40	40	40	40	40	39										40
B 130				38	37	37	36	36	37	35	35	35	35	35	35						36
B 118				36	35	35	35	35	34	34	35	36									35
B 129			37	37	37	37	36	33	34	35	36				34	36					36
B 112	35	35	36	35	36	35	35	36	35	35	35										36
B 124				36	35	35	34	35	35	35	34	34	34	34							35
B 126			39	39	38	38	39	39	38	38	38	37	37								38
B 136			34	35	35	34	35	35	33	35	34	34	34								35
B3533		37	37	37	37	37	37	38		37			37								37
B2107			35	36	36	36	37	36	35	35	35	34	35								36
B2798				38	36	37	38	38	37	36	35	36	36								37
B2817			43		43	43	42	39	40	40	39	37	40	38		40					40
B2816		39	40		40	40	39	38	39	38	39		39								39
B2739				37	38	38	37	36	36	36	37		36								37
B2067		36	36	38	36	35	34	35	35	36	36	36									36
B2375			37	36	35	35	35	35	35	35	35	35	35								35
B2186		41	39		38	39	37	37		37	36	35	36	36							38
B2333		36	36	35	35	35	35	34	35	36	35	35		34							34
B3361			38	37	36	38	37	37	37	38	37	37	37								37
B2656			36	35	36	37	37	36	37	36	36	35	35	36	36	34					36
B2601		37	38	37	37	36	37	35	35	34	35	35									36
B2357		36		36	36		35	35	35	35	32	35	34	35	34						36
B2440						35	35	35	35	35	35	36	38	39	37	36					36
B2035	40	41	40	41	39	39	39	37	37	37	37	37	38								39
B1984	39		36	37	37	37	37	39	36	39	42										38
Min.	35	35	34	35	35	34	34	33	33	34	34	34	34	34	34	34					
Max.	40	43	43	44	44	43	43	43	43	42	33	43	42	42	42	40					
Mean	38	38	38	38	37	37	37	37	37	36	37	36	37	36	36	36					

PERCENTAGE OF SO-SE TO THE TOTAL CRANIAL BASE

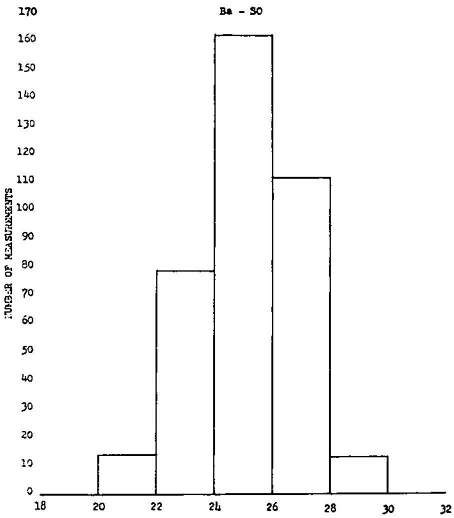

Fig.2. Frequency distribution of percentage contributed by Ba-SO to the total cranial base.

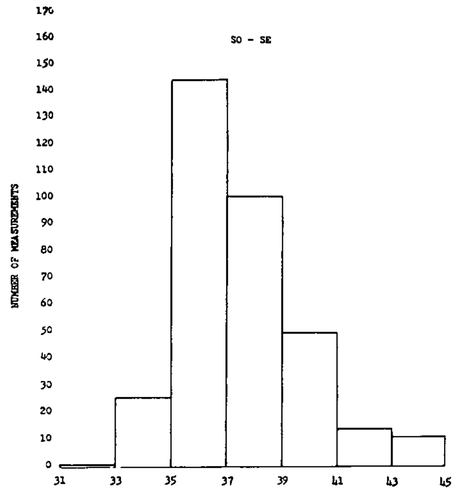

Fig. 3. Frequency distribution of percentage contributed by SO-SE to the total cranial base.

TABLE III

Case No.	*Age* 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Av.
B3149				38	38	38	37	39	39	39	40	40	39	41	42	41		41			39
B3019			40	39	40	38	40	40	38	40	39	40	40		40						39
B 114			39	39	40	39	38	39	39	38	39	38	38								39
B 107				34	35	35	34	34	35	35	35	35	35	35	35						35
B2301				38	38	38	39	38	38	38	38	40		40							38
B2441		33	34	35	36	36	36	36	36	36	36										36
B 130				38	39	38	39	38	37	39	38	39	39	39	40						39
B 118				37	38	38	38	37	39	39	39	38									38
B 129			40	40	40	39	40		40	40	40				41	39					40
B 112	38	38	38	38	37	38	38	37	37	38	38										38
B 124				38	40	40	40	39	39	39	39	39	40	40							39
B 126			36	36	37	37	36	37	37	37	37	37	38	40							37
B 136			38	37	38	39	38	38	38	38	38	39	39								38
B3533		42	42	42	42	42	41	39		39			39								41
B2107			41	39	39	39	38	39	40	40	40	41	40								39
B2798				38	38	38	37	37	37	38	37	37	37								37
B2817			35		35	35	35	37	37	36	36	37	36			36					36
B2816		38	38		37	37	38	37	37	37	36		36								37
B2739				38	38	38	39	40	41	41	40		40								39
B2067		38	38	26	38	37	37	38	37	38	36	37	37								37
B2375			38	38	38	38	38	38	38	38	38		39								38
B2186		37	37		37		37	37		39	39	39	38	38							37
B2333		42	42	42	42	42	41	42	42	41	41	41		43							42
B3361			39	38	39	39	38	39	39	38	39	39	39								39
B2656			38	38	37	38	37	39	37	39	39	39	37	36	37	39					38
B2601		39	38	39	39	38	39	39	38	40	39	38									39
B2357		40		39	40	40	41	41	40	41	41	41	41	42	41						40
B2440						39	38	38	38	39	39	39	38	37	38	38					38
B2035	38	38	37	37	39	39	39	39	39	40	39	39	39								38
B1984	38	38	37	38	37	38	39	38	38	39											38
Min.	38	33	34	34	35	35	34	34	35	35	35	35	35	35	35	36					
Max.	38	42	42	42	42	42	41	42	42	41	41	41	41	43	41	41					
Mean	38	38	38	38	38	38	38	38	38	39	38	39	38	39	39	39					

PERCENTAGE OF SE-Na TO THE TOTAL CRANIAL BASE

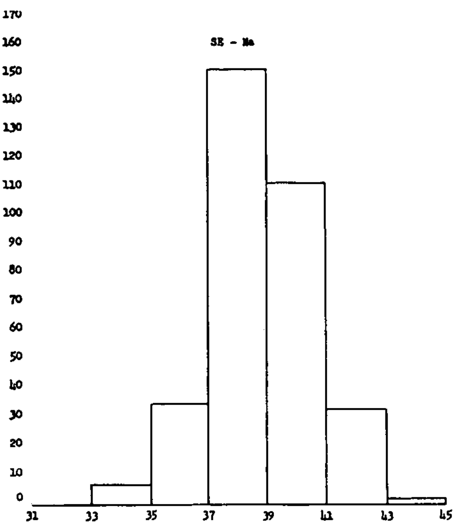

Fig. 4. Frequency distribution of percentage contributed by SE-Na to the total cranial base.

The cranial base length was approximately doubled over the postnatal growth period. The resulting curve resembled the neural type described by Scammon ('36), (Fig. 10). At approximately 3 years of age more than 50 percent of complete growth was attained and almost 90 percent of growth was completed by the 13th year.

VI. Discussion

In the growth and development of the skull the growth of any one part is associated with adjustments in contiguous structures. In discussing this integrative growth, Todd ('32) stated that increase in dimensions, change in proportions, and adjustments of parts, occurred. This is borne out in the study of the face.

TABLE IV

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Min.	Max.	Inc. Dec.	Av. Deg.
B3149				133	132	133	135	130	133	132	133	129	132	130	130	131	130	133	—3	132
B3019			132	131	135	135	133	133	130	131	128	126	125		125		125	133	—8	131
B 114			118	125	125	125	122	123	124	123	123	123	121				123	125	—2	123
B 107				133	135	135	138	138	137	138	138	138	138	137	138		133	138	+5	137
B2301				127	127	127	127	127	127	127	127	128		124			127	128	+1	127
B2441		128	128	127	125	126	124	123	122	122	121		122				122	128	—6	125
B 130				128	128	128	128	129	129	128	129	130	131	131	130		128	130	+2	129
B 118				139	140	140	140	139	140	139	140	140					139	140	+1	140
B 129			127	128	127	120	129	130	129	130	129				129	129	127	129	+2	129
B 112	134	134	137	138	139	139	141	142	142	141	141						134	141	+7	138
B 124				130	131	131	130	130	130	130	129	130	131	139			130	130	0	130
B 126			121	120	120	121	120	120	121	122	122	122	122	121			121	121	0	121
B 136			125	125	126	127	127	129	128	127	128	128	129				125	129	+4	127
B3533		122	122	122	122	122	124	122		120			123				122	123	+1	122
B2107			127	125	125	125	124	125	126	125	126	126	126				126	126	0	126
B2798				128	127	127	128	128	128	127	127	128	129				128	129	+1	128
B2817			121		121	121	122	121	122	122	121		122	122		121	121	121	0	121
B2816		126	127		129	131	130	129	131	130	130		129				126	129	+3	129
B2739				130	129	129	130	128	130	130	130	130	131				130	131	+1	130
B2067		135	135	133	131	130	131	131	130	130	131	130	132				132	135	—3	131
B2375			130	131	131	131	131	132	131	131	132	132	131				130	131	+1	131
B2186		132	131		131	130	132	130		131	130	131	131	131			131	132	—1	131
B2333		132	132	132	132	132	132	134	134	134	135	135		135			132	135	+3	133
B3361			143	143	143	143	143	143	143	143	143	143	143				143	143	0	143
B2656			129	129	130	128	129	129	129	129	129	129	132	132	134	135	129	135	+6	130
B2601		132	131	131	133	133	133	132	132	132	130	130					130	132	—2	132
B2357		131		130	130	132	130	130	130	132	133	133	133	132	133		130	133	+3	131
B2440						129	130	130	130	130	131	132	131	131	132	132	129	132	+3	131
B2035	136	133	133	133	132	134	132	131	130	130	129	127	127	127			127	136	—9	133
B1984	127	124	124	124	125	124	123	123	123	122	123						123	127	—4	124
Min.	127	122	121	120	120	121	120	120	121	122	122	122	122	121	125	121				
Max.	136	135	143	143	143	143	143	143	143	143	143	143	143	137	138	135				
Mean	132	130	132	130	130	130	130	129	130	130	130	130	129	130	131	130				

Cranial Base Angle Ba-S-Na in Degrees

In the calvarium, however, although there are increases in dimensions, there are relatively few changes in the proportions of the parts and, therefore, relatively little adjustment of parts is required. From the present study it is

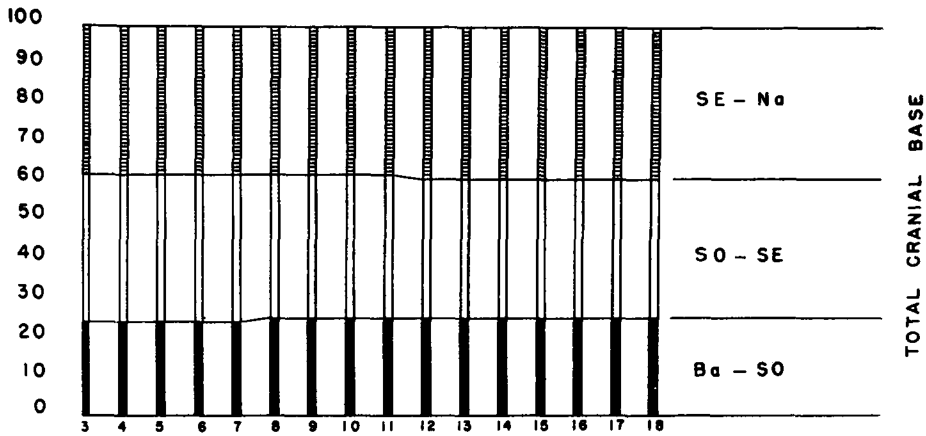

Fig. 5. Mean relative proportion of components of cranial base from the 3rd to the 18th year. Figures on left indicate percentages.

TABLE V

Case No.	*Age* 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
B 112	96	100	103	104	106	108	110	112	115	115						
B3361			100	105	108	110	112	114	118	118	122	122	122			
B2333		102	104	106	109	109	112	114	114	114	116	116				
B2817			114	116	118	122	125	126	126	129	130	134	134	134	135	136
B2375			108	111	114	114	117	119	119	121	121	121	121			
B2067		111	112	114	116	118	122	122	123	125	130	131	133			
B2739				109	111	111	114	117	118	118	118	118	118			
B2816		110	111	114	117	117	118	121	124	124	127		132			
B2186		98	103	108	110	110	111	114	114	114	116	118	122	123		
B2601		103	105	108	108	110	110	114	115	115	115	116				
B 107				106	108	108	111	112	112	113	117	117	117	117		
B2301				107	112	117	117	117	120	122	122	124	124			
B 130				104	105	107	111	113	113	113	114	116	118	120	120	
B3149				113	116	117	119	121	125	125	125	126	132	134	134	135
B3019			110	113	113	115	118	120	121	121	125	124	126	129	131	
B 118				111	112	113	115	116	118	118	122	123				
B 129			112	113	115	116	117	119	122	122	122	126	128			
B 124				104	104	105	110	111	111	111	114	115	115	115		
B 136			119	119	119	125	125	125	125	126	129	129	130			
B2107		103	104	107	110	110	113	117	119	121	121	121	122			
B2035	99	100	105	107	111	112	113	116	116	117	118	121	123			
B2440						113	117	117	117	121	121	121	121	121	121	121
B2357		99	103	107	108	109	109	112	114	116	116	116	118	116	116	
B2798				107	108	110	113	113	116	117	118	120	123	125		
B3633			110	112	114	116	117	120	121	122			130			
B 126			106	111	113	114	118	121	121	122	124	126	129			
B 114				119	121	127	127	129	132	133	134	137	138			
B2441		102	105	107	110	112	113	118	119	121	125	128	131			
B2656		113	113	115	119	121	121	124	128	129	131	133	136	130	141	141
Mean	98	104	108	110	112	114	116	118	119	119	122	123	126	126	128	133
S.D.±		5.2	5.0	4.4	4.4	5.5	4.5	4.5	5.0	5.5	5.6	6.1	6.6	8.5		

LENGTH OF CRANIAL BASE IN MILLIMETERS

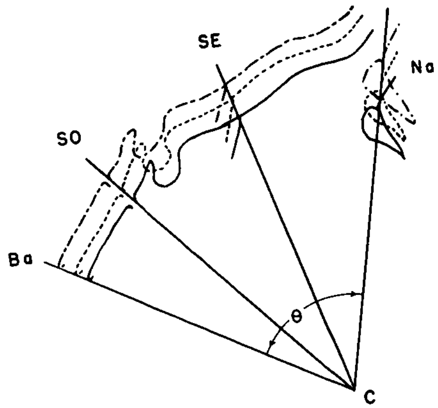

Fig. 6. Tracings of cranial base of same individual at 5, 8, and 11 years, showing maintenance of concentricity and proportionality (B 3361, W.R.U.).

TABLE VI

MEAN PERCENTAGE, RANGE, AND STANDARD DEVIATION OF EACH COMPONENT OF THE CRANIAL BASE.

	Ba-SO	*SO-SE*	*SE-Na*
Mean	25%	37%	38%
Range	21-28%	33-44%	34-44%
S. D.	±1.7%	±2.1%	±1.8%

seen that the ratio between each part of the cranial base and the whole was essentially unchanged throughout growth. Brodie ('41) showed that after three months of age the external conformation of the skull was determined and thereafter did not change. Here too, the relative growth of the parts must therefore remain unchanged. Since the structures of the face are continuous with those of the cranial base, their growth is related to growth in the cranial base.

The upper face is attached to the anterior base through sutures at the fronto-nasal junction anteriorly, at the zygoma laterally and through the pterygoid plates posteriorly. The face can be considered as an outgrowth of the underside of the cranium. While it is influenced by the proportional increases in the anterior and posterior bases, any additional downward and forward growth must take place at the sutures mentioned above which lie outside of the calvarium.

The growth of the mandible must be integrated with that of the posterior cranial base since it articulates with the glenoid fossa of the temporal bone which travels with the occipital bone. It must, therefore, keep pace with the dorsal growth of the posterior cranial base as well as with the growth of the anterior cranial base in order to maintain its relation with the upper face and the maxillary dental arch.

As a corollary, if one part of the cranial base did change in its relation to the whole, it would be manifested in that part of the face to which it is attached. For example, if the basilar part of the occipital bone were smaller in proportion than normal it would have an effect not only on the cranium but on the lower face as well.

A significant change in the deflection angle Ba-S-Na was observed in 1/6 of

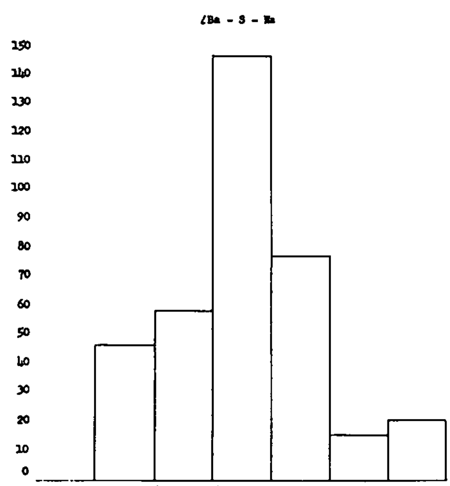

Fig. 7. Frequency distribution of cranial base angle Ba-S-Na in degrees. Figures on left indicate number of measurements.

the cases in this series. Eight cases showed a decrease, while ten cases showed an increase. This may have been due to the use of an external landmark (Na). However, even with a change in the deflection angle whether it was in increase or a decrease, there were no corresponding changes in the proportions contributed by the components of the cranial base. In these cases it is believed that there was readjustment of parts but little increase in dimensions. Further evidence which may bring light on the effects of changes in this angle and on other areas of the face is needed. Furthermore, such effects should be studied in those cases where the cranial base shows aberrant growth.

Scammon ('36) attributed a characteristic growth pattern to the neural structures. This growth curve was followed by the brain, the spinal cord and the membranes covering it, the eye with its several parts and the auditory mechanism. It is characterized by a gradual deceleration from birth to the period of 90 percent of final growth attainment at 7-10 years. The incremental growth of the cranial base conforms quite closely to this neural pattern. When the incremental curve is plotted as percentage of total attainment (Fig. 10) this is more readily evident. In a less striking manner cranial bone growth is also allied to general body growth patterns. A plateau occurs around puberty and this is followed by a parapubertal acceleration in most cases. This may be related to endocrine influences during this period. Some heterogeneity in the growth pattern is to be expected since the cranial base is also contiguous with the face. The rate of growth of the face after seven years is much greater than that of the brain. The cranial base, which is the hafting zone between the cranium and the face, seems to reflect the behavior of the growth patterns of both.

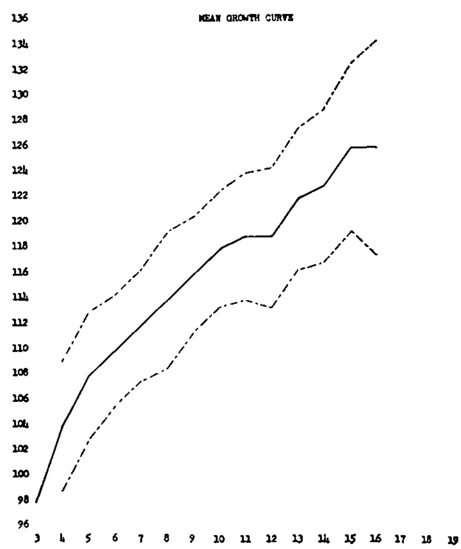

Fig. 8. Incremental growth of the cranial base of the sample from the 3rd to the 18th year. Broken lines indicate Standard Deviation. Figures on left indicate length in mm.

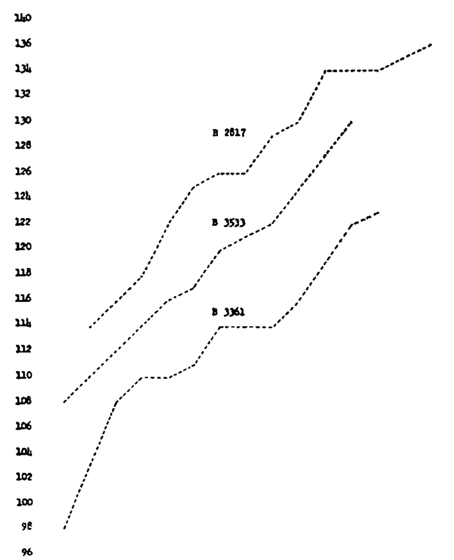

Fig. 9. Incremental growth of cranial base of three typical cases from the 4th to the 18th year. Figures on left indicate millimeters.

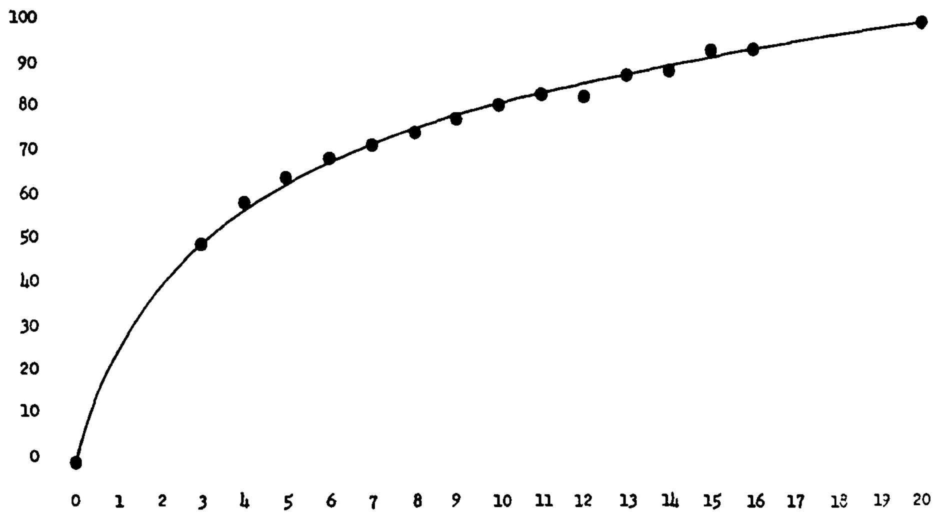

Fig. 10. Percentage attainment of cranial base length at successive age stages from birth to 20th year.

VII. Summary and Conclusions

I. Serial cephalometric roentgenograms were employed to measure the incremental growth of the cranial base and the relative contribution made by each part of the cranial base to the whole.

II. In any individual the relative contribution of each part remained virtually constant throughout the period studied. The contribution for the posterior part (Ba-So), was 25%; for the sphenoidal part (SO-SE), it was 37%; and for the anterior part (SE-Na), it was 38%. This constancy in relation was maintained in the entire group over the age range from 3 to 18 years.

III. The pattern of incremental growth of the cranial base was characterized by (a) rapid growth from birth to 5 years, (b) deceleration between 5 and 12 years with plateauing between 10 and 13 years, (c) a parapubertal acceleration and then (d) gradual deceleration.

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