Craniofacial Height and Depth Increments in Normal Children

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The changes from three to eight years in the height and the depth of the craniofacial area in normal Melbourne children have been studied. It was expected that this would provide information about relative rates of bone growth in particular directions that could be useful in predicting adult facial patterns. The method of analysis employed was that used by Coben;[1] the present findings have been compared with those reported by him for American children studied at the ages of eight and sixteen years.

Coben's method has antecedents in art history (Piero della Francesca, Albrecht Dürer), in comparative taxonomy, (Thompson[2]), in anthropometry (Lucae), and in orthodontic analyses (de Coster[3,4]). In his classic, *On Growth and Form,* Thompson[2] used a system of coordinate analysis when he attempted a mathematical interpretation of shape differences between species. DeCoster[3,4] drew normal schema of coordinate lines for age levels between four and twenty years of hand-wrist skeletal age. The outline of the face of a child with malocclusion or a growth defect was drawn on a normal schema of lines; later the lines were deformed to pass through chosen points. The extent of the deformation of the lines could be used to estimate the variation from the normal schema for that age.

MATERIAL AND METHODS

The children studied were normal Australians (twenty-six males, twenty-six females) of British ethnic origin, enrolled in the Melbourne Child Growth Study.[5] None of these children received orthodontic treatment before or during the study. These children varied in socio-economic status: Ten were children of professional class parents, thirty-three were children of skilled tradesmen and nine were children of unskilled workers.

Two Broadbent-Bolton cephalometric radiographs of each child were studied, the first taken at about the age of three years, the second taken at about the age of eight years. The mean ages were 3.80 and 8.04 years in the boys and 3.46 and 8.02 in the girls. The following points, planes and angles were used: orbitale, porion, nasion, anterior nasal spine, subspinale, pogonion, gonion, articulare, menton, basion, sella turcica, pterygomaxillary fissure, Frankfort horizontal plane, facial plane, mandibular plane, facial angle, angle of convexity, mandibular plane angle, gonial angle and angle of ramus inclination. Some of these planes and angles are shown in Figure 1. All of them have been identified on tracings according to well-known accepted definitions and criteria (e.g., Downs[6]); for points not in the midline, averages between the two sides were used. The only measurement that may require definition is the angle of ramus inclination. This angle, representing the anterior inclination of the ramus (Fig. 1), is the angle between the ramus plane (AR-GO) and a line perpendicular to the Frankfort horizontal plane (Coben). It is found by substracting the sum of the mandibular plane angle and 90° from the gonial angle, i.e., the ramus inclination angle = gonial angle — (90° + mandibular plane angle).

The Frankfort horizontal plane (FH)

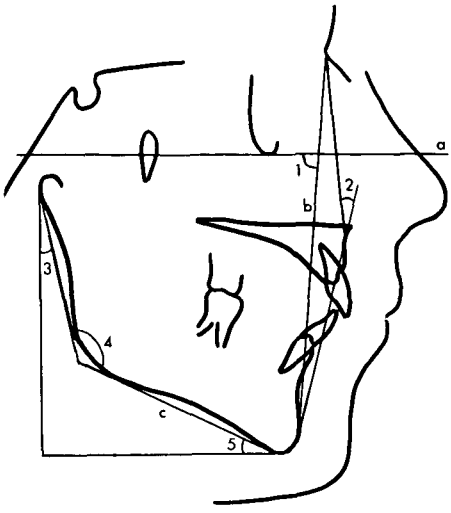

Fig. 1 The angles and planes used in the present analysis: 1. facial angle, 2. angle of convexity, 3. angle of ramus inclination, 4. gonial angle, 5. mandibular plane angle, (a) Frankfort horizontal plane, (b) facial plane, (c) mandibular plane.

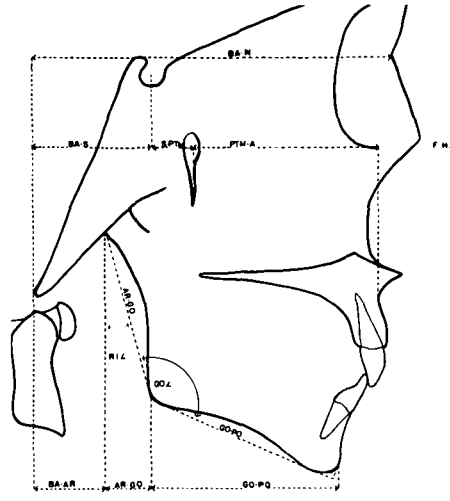

Fig. 2 The projected and actual measurements used in the analysis of craniofacial depth.

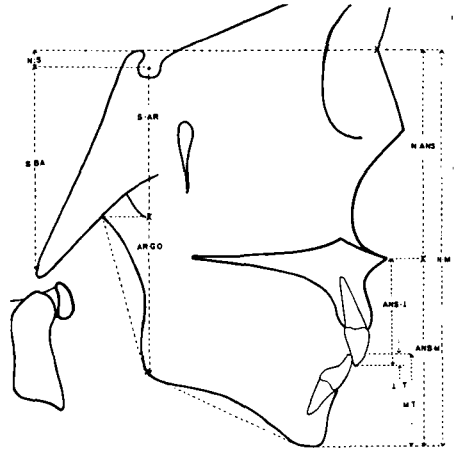

Fig. 3 The projected measurements used in the analysis of craniofacial height.

was used for orientation although porion was difficult to locate in some radiographs. Its position was checked by examining the series of annual radiographs for each child and by determining the angle between the Frankfort horizontal and the sella nasion planes in each of these. This angle is constant.

Measurements of craniofacial depth were made parallel to FH and vertical height measurements perpendicular to FH in accordance with Coben's method (Figs. 2 and 3). The length BA-N, projected to the Frankfort horizontal plane, was taken as the depth of the cranial base. The depth of the middle part of the face (BA-A) and its component parts (BA-S, S-PTM, and PTM-A) were expressed as percentages of the base depth (BA-N) as were the mandibular depths (AR-GO, GO-PO). The vertical height measurements were expressed as percentages of the total anterior face height (N-M). The anterior face measurements included the upper anterior face height (N-ANS) and the lower anterior face height (ANS-M). The latter includes ANS-$\underline{1}$, $\underline{1}$-$\bar{1}$, and M-$\bar{1}$. The posterior face height measurements included S-AR, AR-GO and S-BA. The cranial base height (N-S) was measured also. The depth of AR-GO and GO-PO have been recorded as measurements projected to the Frankfort horizontal plane. In addition, they have been recorded as absolute lengths. Throughout the tables

and the text the absolute lengths of these measurements are designated as A.L.

Findings

Craniofacial Depth Proportions

In Tables I and II, the distance BA-N was recorded as the actual measurement in millimeters projected to the Frankfort horizontal plane. All other depth distances were measured parallel to the Frankfort horizontal plane and recorded as percentages of BA-N (Tables I and II). The absolute sizes of the angles were recorded in degrees. The large standard deviations, *relative to the means,* indicate a marked variability of craniofacial depth proportions in both the boys and the girls at each age studied.

The findings for boys and girls at three years indicate that the mean projected BA-N was slightly larger in the boys than the girls but the girls varied more in this measurement than did the boys. Because this length was used to express other lengths in a proportionate fashion, lengths that were proportionately similar in the two sexes would have been absolutely larger in the boys than in the girls.

The sex differences in proportion were very small except for AR-PO and BA-PO; the means for both of these were larger in the boys than the girls but in each sex these were highly variable proportions, as indicated by their large standard deviations. The findings lead to the general conclusion that at about three years the mean craniofacial depths from BA to N and PO were greater in the boys than in the girls. In association with this, the mean facial angle was slightly smaller in the boys than in the girls. Apparently, the sex difference in mandibular size was not great enough to compensate for the greater depth of the basisphenoid and basiocciput in the boys.

At eight years (Table II) the mean length BA-N was slightly larger in the boys than in the girls and was markedly variable in each sex. There was little sex difference in the mean craniofacial depth proportions except in AR-PO, AR-GO (A.L.) and GO-PO; each of these means was larger in the boys than the girls. However, these dimensions were very variable and the observed sex differences were not statistically significant. Most of the mean craniofacial depths in the upper face (BA-N, S-PTM, PTM-A, BA-A) tended to be larger in the boys than the girls.

The mean proportionate distance BA-AR was larger in the girls than the boys although the mean ramus inclination angle was smaller in the girls than in the boys. Presumably because of the larger mean ramus inclination angle and the greater length of the ramus in the boys, the mean proportionate distance AR-GO was larger in the boys than in the girls. The mean absolute length of the body of the mandible (GO-PO) was larger in the boys than in the girls, but the mean proportionate lengths were similar in the two sexes. The mean facial angles were approximately the same in the two sexes despite the slight tendency in the boys for PO to be more anterior, relative to BA. The mean angle of convexity was only slightly larger in the boys than in the girls but this tendency was in the direction expected from the sex difference in the mean proportionate distance BA-A.

Depth Increments from Three to Eight Years

In each sex (Tables I and II) there were marked increases in BA-N and, because most linear depth measurements were expressed proportionately to BA-N, some decreases were observed. There were proportionate decreases in the mean total depth (BA-A), due mainly to a large decrease in the proportionate distance S-PTM, which was

TABLE I

CRANIOFACIAL DEPTH PROPORTIONS IN 26 BOYS (MEAN AGE 3.8 YEARS) AND 26 GIRLS (MEAN AGE 3.46 YEARS)

MEASUREMENT	UNIT	Boys		Girls	
		Mean	s.d.	Mean	s.d.
BA-N	mm	79.52	2.92	76.91	3.72
BA-S	% BA-N	24.02	2.52	23.52	2.60
S-PTM	% BA-N	24.24	2.34	24.26	2.98
PTM-A	% BA-N	53.40	3.45	53.30	3.67
BA-A	% BA-N	101.68	3.08	101.09	3.52
BA-AR	% BA-N	11.29	2.75	11.33	2.72
AR-PO	% BA-N	82.06	5.33	80.22	6.65
BA-PO	% BA-N	93.08	5.33	91.57	5.75
AR-GO (A.L.)	% BA-N	45.07	2.86	44.12	3.01
Ramus inclination angle	degrees	20.83	4.36	20.63	4.60
AR-GO	% BA-N	15.85	3.50	15.03	3.28
GO-PO (A.L.)	% BA-N	65.86	4.15	65.18	4.23
Mandibular plane angle	degrees	25.40	4.20	25.79	4.65
GO-PO	% BA-N	65.48	4.66	65.20	5.21
Gonial angle	degrees	136.62	4.95	136.42	5.77
Facial angle	degrees	84.38	2.67	85.44	3.25
Convexity angle	degrees	12.33	3.90	11.75	4.50

A.L. = Absolute Length.

TABLE II

CRANIOFACIAL DEPTH PROPORTIONS IN 26 BOYS (MEAN AGE 8.04 YEARS) AND 26 GIRLS (MEAN AGE 8.02 YEARS)

MEASUREMENT	UNIT	Boys		Girls	
		Mean	s.d.	Mean	s.d.
BA-N	mm	85.97	3.95	84.65	3.93
BA-S	% BA-N	24.40	2.79	24.42	2.52
S-PTM	% BA-N	22.38	2.36	22.20	2.16
PTM-A	% BA-N	53.41	3.03	52.49	3.24
BA-A	% BA-N	100.17	3.04	99.11	2.45
BA-AR	% BA-N	9.98	3.08	10.62	2.46
AR-PO	% BA-N	83.61	5.74	82.20	6.43
BA-PO	% BA-N	93.60	5.02	92.83	5.70
AR-GO (A. L.)	% BA-N	45.59	3.17	44.38	3.08
Ramus inclination angle	degrees	16.30	4.45	15.73	4.60
AR-GO	% BA-N	12.41	4.17	11.81	3.52
GO-PO (A.L.)	% BA-N	73.34	5.38	70.62	4.78
Mandibular plane angle	degrees	26.71	4.35	26.60	4.44
GO-PO	% BA-N	70.75	4.47	70.39	5.12
Gonial angle	degrees	133.00	5.17	132.33	6.11
Facial angle	degrees	86.67	2.35	86.35	3.31
Convexity angle	degrees	7.52	4.35	6.75	4.57

A.L. = Absolute Length.

not completely offset by the small proportionate increase in BA-S. In the mandibular area there was a small proportionate increase in BA-PO that was larger in the girls than the boys. In each sex the components of this measurement varied in mean increments; BA-AR decreased and AR-PO increased but the mean decrease in BA-AR was less in the girls than the boys. Furthermore, the increase in AR-PO was associated with a large increase in GO-PO. The mean absolute measurements of the mandible increased more in the boys than in the girls; the sex difference was very small for the ramus height but was considerable for the body length. The greater proportionate growth in mandibular body length in the boys was reflected in their larger increase in the mean facial angle. The absolute measurements of the mandible, AR-GO and GO-PO, differed in their change of proportion. The mean change in GO-PO was approximately fifteen times as great as that in AR-GO, indicating much more rapid growth in mandibular body length than in mandibular ramus height.

The mean facial angle increased more in the boys than in the girls and there was a not unexpected associated decrease in the mean angle of convexity in each sex. In the girls the decrease in the mean angle of convexity was presumably due to a slow anterior movement of A that was reflected also in decreases in the proportionate distances BA-A and PTM-A. There were decreases in the mean ramus inclination angles and gonial angles but there were only slight changes in the mean mandibular plane angles.

These increments have been divided by the mean age interval between the two sets of radiographs to provide mean annual increments from three to eight years. Similarly, mean annual increments for eight to sixteen years have been obtained from the data of Coben (Table III). In each sex the rate of increase was greater during the younger age interval for most linear dimensions although some of the differences were small (e.g., BA-A). In some mandibular dimensions the rate of increase was more rapid during the later interval (e.g., S-PTM, AR-PO [A.L.], AR-GO). The mean ramus inclination angle decreased quite rapidly during three to eight years but only slowly from then to sixteen years. In the boys and the girls the mean mandibular plane angle increased slightly during the younger age interval but decreased during the older interval. The mean gonial angle decreased at similar annual rates in each sex during both intervals.

These mean annual increments during successive age intervals are based on data from two samples of children. It is of interest, therefore, to compare the means for the two groups at the age of eight years (Table IV). The present children, in comparison with those studied by Coben (combined boys and girls), had a larger mean BA-N due mainly to differences in S-PTM and PTM-A. The present children had larger mean proportions for BA-A, BA-PO, and for AR-GO but not for GO-PO. The larger mean proportion AR-GO was associated with a larger mean ramus inclination angle and a larger gonial angle but not with large mean differences in AR-GO (A.L.).

Craniofacial Height Proportions

These were expressed as proportions of N-M. The distance N-M was expressed as a proportion of BA-N. The mean proportionate distances at three years (Table V) showed only small sex differences except for N-M and N-S, which were larger in the boys and N-ANS, $\underline{1}$-$\bar{1}$ and ANS-M, which were larger in the girls. At eight years (Table VI) the means were larger in

TABLE III

MEAN ANNUAL INCREMENTS IN CRANIOFACIAL DEPTH

MEASUREMENT	Present Group		Coben[1]	
	Boys	Girls	Boys	Girls
BA-N	1.5 mm	1.71 mm	1.2 mm	.96 mm
BA-S	.55 mm	.58 mm	.36 mm	.39 mm
S-PTM	0.00 mm	.02 mm	.21 mm	.14 mm
PTM-A	.81 mm	.78 mm	.71 mm	.52 mm
BA-A	1.26 mm	1.38 mm	1.29 mm	1.06 mm
BA-AR	-.10 mm	.07 mm	0.00 mm	0.00 mm
AR-PO	1.62 mm	1.76 mm	1.78 mm	1.49 mm
BA-PO	1.55 mm	1.82 mm	1.78 mm	1.49 mm
AR-PO (A.L.)	.81 mm	.80 mm	1.53 mm	1.18 mm
Ramus inclination angle	-1.05 °	-1.09 °	-.17 °	-.09 °
AR-GO	- .45 mm	- .36 mm	.10 mm	.16 mm
GO-PO (A.L.)	2.64 mm	2.22 mm	1.62 mm	1.23 mm
Mandibular plane angle	.36 °	.20 °	-.43 °	-.53 °
GO-PO	2.05 mm	2.00 mm	1.68 mm	1.34 mm
Gonial angle	-.74 °	-.91 °	-.60 °	-.62 °

A. L. = Absolute Length.

TABLE IV

COMPARISON BETWEEN MEANS AND STANDARD DEVIATIONS IN CRANIOFACIAL DEPTH PROPORTIONS IN THE PRESENT STUDY AND IN THE STUDY BY COBEN (1955) AT EIGHT YEARS

MEASUREMENT	Boys		Girls		Coben[1] Boys & Girls	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
BA-N	85.97	3.95	84.65	3.93	83.1	3.75
BA-S	24.40	2.79	24.42	2.52	24.9	2.19
S-PTM	22.38	2.36	22.20	2.16	20.7	2.82
PTM-A	53.41	3.03	52.49	3.24	51.4	2.59
BA-A	100.17	3.04	99.11	2.45	97.0	3.24
BA-AR	9.98	3.08	10.62	2.46	9.9	2.63
AR-PO	83.61	5.74	82.20	6.43	80.2	6.48
BA-PO	93.60	5.02	92.83	5.70	90.1	6.38
AR-GO (A.L.)	45.59	3.17	44.38	3.08	45.2	3.20
Ramus inclination angle	16.30	4.45	15.73	4.60	9.8	4.98
AR-GO	12.41	4.17	11.81	3.52	7.6	3.95
GO-PO (A.L.)	73.34	5.38	70.62	4.78	76.9	3.99
Mandibular plane angle	26.71	4.35	26.60	4.44	26.4	4.07
GO-PO	70.75	4.47	70.39	5.12	72.6	4.44
Gonial angle	133.00	5.17	132.33	6.11	126.2	5.41
Facial angle	86.67	2.35	86.35	3.31	84.8	3.37
Convexity angle	7.52	4.35	6.75	4.57	4.8	4.14

A.L. = Absolute Length.

TABLE V

CRANIOFACIAL HEIGHT PROPORTIONS IN 26 BOYS (MEAN AGE 3.8 YEARS) AND 26 GIRLS (MEAN AGE 3.46 YEARS)

MEASUREMENT	UNIT	Boys		Girls	
		Mean	s.d.	Mean	s.d.
N-S	% N-M	12.40	3.19	10.94	3.90
S-AR	% N-M	26.47	2.26	26.12	2.65
AR-GO	% N-M	36.1	2.72	36.99	2.98
S-GO	% N-M	62.9	1.21	63.11	3.80
N-ANS	% N-M	42.08	1.62	43.18	1.98
ANS-$\underline{1}$	% N-M	25.29	1.67	25.03	1.97
M-$\bar{1}$	% N-M	33.88	1.46	34.19	1.21
$\underline{1}$-$\bar{1}$	% N-M	1.82	1.29	2.37	1.85
ANS-M	% N-M	57.9	1.62	56.82	1.98
N-M	% BA-N	116.94	5.25	112.31	6.41

the boys than the girls for N-M and for all the components of lower anterior face height (ANS-$\underline{1}$, M-$\bar{1}$, $\underline{1}$-T, ANS-M). Whereas the means for lower anterior face height (ANS-M) tended to be larger in the boys than the girls at each age, those for upper anterior face height (N-ANS) tended to be larger in the girls.

At three years the mean proportion ANS-$\underline{1}$ was slightly greater in the boys

TABLE VI

CRANIOFACIAL HEIGHT PROPORTIONS IN 26 BOYS (MEAN AGE 8.04 YEARS) AND 26 GIRLS (MEAN AGE 8.02 YEARS)

MEASUREMENT	UNIT	Boys		Girls	
		Mean	s.d.	Mean	s.d.
N-S	% N-M	10.60	3.18	10.38	2.92
S-AR	% N-M	26.78	2.53	26.37	3.13
AR-GO	% N-M	36.02	2.62	36.30	2.96
S-GO	% N-M	62.81	3.05	62.73	3.96
N-ANS	% N-M	44.28	2.02	45.22	2.03
ANS-$\underline{1}$	% N-M	25.46	1.81	24.00	2.11
M-$\bar{1}$	% N-M	34.10	2.00	33.39	1.45
$\underline{1}$-$\bar{1}$	% N-M	3.33	1.73	2.61	1.94
ANS-M	% N-M	56.42	3.02	54.78	2.03
N-M	%BA-N	120.79	6.43	117.83	5.73

TABLE VII

MEAN ANNUAL INCREMENTS IN CRANIOFACIAL HEIGHT

MEASUREMENT	Present Group		Coben[1]	
	Boys	Girls	Boys	Girls
N-S	-.12 mm	.20 mm	.12 mm	.08 mm
S-AR	.76 mm	.82 mm	.66 mm	.36 mm
AR-GO	.95 mm	.96 mm	1.51 mm	1.18 mm
S-GO	1.62 mm	1.78 mm	2.17 mm	1.55 mm
N-ANS	1.64 mm	1.76 mm	1.17 mm	.74 mm
ANS-$\underline{1}$	.71 mm	.51 mm	.49 mm	.34 mm
M-$\bar{1}$	.93 mm	.84 mm	.92 mm	.57 mm
$\underline{1}$-$\bar{1}$	.45 mm	.13 mm	.10 mm	.31 mm
ANS-M	1.12 mm	1.24 mm	1.31 mm	.75 mm
N-M	2.62 mm	2.98 mm	2.48 mm	1.49 mm

but at eight years the sex difference was marked. At each age in the girls the mean proportionate difference $\underline{1}$-$\bar{1}$ tended to be larger than in the boys; this would have reduced their face height.

Increments from three to eight years

All of the increments were positive in each sex except for N-S which decreased slightly in the boys. The largest increments from three to eight years occurred in S-GO, N-ANS, ANS-M and N-M. The mean increment N-ANS exceeded that for ANS-M in each sex.

These increments for the total period have been expressed as mean annual increments in Table VII. For corresponding measurements the mean annual increments were similar in the two sexes except for N-S (larger in girls) and ANS-$\underline{1}$ and $\underline{1}$-$\bar{1}$ which were larger in boys. The relative difference between the sexes in mean annual increments for $\underline{1}$-$\bar{1}$ was particularly large, being .45 mm in the boys but only .13 mm in the girls.

The mean increments in craniofacial height proportions for the present sample have been compared with those

TABLE VIII

COMPARISON BETWEEN MEANS AND STANDARD DEVIATIONS IN CRANIOFACIAL HEIGHT PROPORTIONS AT EIGHT YEARS IN THE PRESENT STUDY AND IN THE STUDY BY COBEN (1955)

MEASUREMENT	PRESENT STUDY Boys		PRESENT STUDY Girls		Coben[1] Boys & Girls	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
N-S	10.60	3.18	10.38	2.92	7.1	3.69
S-AR	26.78	2.53	26.37	3.13	26.5	1.79
AR-GO	36.02	2.62	36.30	2.96	38.5	2.76
S-GO	62.81	3.05	62.73	3.96	65.0	3.79
N-ANS	44.28	2.02	45.22	2.03	45.8	2.18
ANS-$\underline{1}$	25.46	1.81	24.00	2.11	23.8	2.18
M-$\overline{1}$	34.10	2.00	33.39	1.45	33.4	1.76
$\underline{1}$-$\overline{1}$	3.33	1.73	2.61	1.94	3.0	2.45
ANS-M	56.42	3.02	54.78	2.03	54.2	2.18
N-M	120.79	6.43	117.83	5.73	115.3	6.56

reported by Coben after reducing each to mean annual increments. For boys the major differences were greater mean increments for N-S, AR-GO and S-GO and smaller increments for N-ANS, ANS-$\underline{1}$ and $\underline{1}$-$\overline{1}$ in the sample of Coben. In the girls there was a larger mean increment for AR-GO in the sample of Coben; all other increments were larger in the present sample.

At eight years most mean height proportions in the present boys and girls were similar to those of the children studied by Coben (Table VIII). One exception is N-S which was markedly larger in the present sample. The greater proportionate height AR-GO and the smaller proportionate depth AR-GO in Coben's sample may be responsible for the smaller mean gonial angle he reported. The mean proportionate height S-GO was smaller in the present children than in Coben's sample. While the mean total face height (N-M) was larger in the present children, the proportion N-ANS was larger in Coben's sample. Other mean facial proportions (ANS-$\underline{1}$ and ANS-M) were larger in the present children than in those studied by Coben.

Variability

The variability of each measurement was large both at three years and at eight years. Amongst measurements of depth, the angle of convexity was particularly variable but GO-PO, AR-PO, and BA-PO were also very variable in both sexes at each age. In height, by far the most variable measurement (taking into account the small size of the mean) was $\underline{1}$-$\overline{1}$, especially at three years when these teeth were in various stages of eruption and occlusion. The other very variable measurements were N-S, N-M,

and AR-GO at each age studied. The coefficients of variability for craniofacial depth and height tended to be larger in the girls than the boys. Those for craniofacial depth proportions were similar at three and eight years, except for slight increases with age in the coefficients for the ramus inclination angle, BA-AR and AR-GO. In the girls, BA-AR was slightly less variable at three years than at eight years. Considering height proportions, $\underline{1}$-$\overline{1}$ and N-S were more variable at three years than at eight years.

A comparison between the variability of craniofacial proportions in the present children at eight years and in the children studied by Coben[1] at the same age shows that, in regard to depth proportions, S-PTM and BA-PO were more variable in Coben's sample and GO-PO (A.L.) was less variable. Among the height proportions, N-S and $\underline{1}$-$\overline{1}$ were more variable in Coben's sample but the total face heights (N-M) and S-AR were less variable. Most other height proportions were similar in variability in the two groups of children.

Segregation Scores

An analysis was made of the extent to which the children studied tended to remain either above or below the mean for each measurement during the period of the study. For each measurement the boys and girls were segregated into four groups:

A. smaller than the mean at three years and larger than the mean at eight years,

B. larger than the mean at three years and larger than the mean at eight years,

C. smaller than the mean at three years and smaller than the mean at eight years,

D. larger than the mean at three years and smaller than the mean at eight years.

For each measurement the number of children in Groups B and C exceeded the number of children in Groups A and D.

In most depth and height proportions (Tables IX, X) it is statistically unlikely that the observed segregations resulted from chance. The directions of the nonrandom features of the segregation scores indicated that, for each proportion, children tended to maintain their position relative to the mean during the age interval three to eight years. Although the segregation scores for most craniofacial depth proportions were statistically significant in each sex, S-PTM was an exception. This may be related to the finding that the mean increment for this dimension was zero or close to zero.

The segregation scores were significant for most craniofacial height proportions with the exception of N-ANS and ANS-M. Since the scores were significant for N-M, this might indicate a variability in vertical level of ANS that could be due to measurement error or variations in growth. Both for height and depth, high levels of statistical significance tended to be more common in the girls than in the boys.

Discussion

Because the craniofacial complex consists of functionally interrelated parts, it would be expected that proportions would provide a better basis for diagnostic analysis than absolute dimensions. The study of increments shows that some proportions do not change, some increase, and some decrease at different times and rates and with different levels of variability. From three to eight years, changes in craniofacial depth proportions varied considerably between different parts of the face. Although the

TABLE IX

PROBABILITY THAT SEGREGATION SCORES FOR CRANIOFACIAL DEPTH RESULTED FROM CHANCE

(See text for details)

MEASUREMENT	Probability	
	Boys	Girls
BA-N	.002**	.002**
BA-S	.002**	.002**
S-PTM	.11	.18
PTM-A	.024*	.040*
BA-A	.014*	.34
BA-AR	.019*	.003**
AR-PO	.026*	.002**
BA-PO	.011*	.015*
AR-GO (A.L.)	.37	.002**
Ramus inclination angle	.001**	.056
AR-GO	.002**	.64
GO-PO (A.L.)	.23	.032*
Mandibular plane angle	.002**	.002**
GO-PO	.020*	.021*
Gonial angle	.012*	.002**
Facial angle	.012*	.002**
Convexity angle	.003**	.008**

A.L. = Absolute Length.

*P. < .05. **P. < .01.

means for total craniofacial depth (BA-N) and total face height (N-M) were larger in the present boys than in the girls at three and at eight years, the mean increments during this period were larger in the girls. The mean present increments in BA-N are similar

TABLE X

PROBABILITY THAT SEGREGATION SCORES FOR CRANIOFACIAL HEIGHT RESULTED FROM CHANCE

(See text for details)

MEASUREMENT	Probability	
	Boys	Girls
N-S	.002**	.21
S-AR	.14	.001**
AR-GO	.32	.002**
S-GO	.21	.001**
N-ANS	.99	.061
ANS-$\underline{1}$	.026*	.002**
M-$\overline{1}$	.001**	.12
$\underline{1}$-$\overline{1}$	.20	.002**
ANS-M	.34	.060
N-M	.009**	.002**

*P. < .05. **P. < .01.

to those reported by Scott[7] from three to seven years for a mixed sample of boys and girls.

The mean annual increments were averaged over the period of the present study and that by Coben although the rate of change might have varied from year to year.

Coben found that males markedly exceeded females in height increments and exceeded them slightly in depth increments. Nanda[8] reported less facial growth in girls than boys during adolescence. In the present study, in each sex, the proportionate depth of the mid-

dle part of the face (BA-A), the gonial angle, the convexity angle and the angle of ramus inclination decreased but the mean depth of the mandibular area (BA-PO) increased slightly and the facial angle increased. The proportionate absolute length of the body of the mandible (GO-PO [A.L.]) increased much more than the absolute length of the ramus.

The finding that the mean increment in GO-PO was greater in the boys than the girls is in agreement with data for five to eleven years and eight to sixteen years (Coben,[1] Meredith[11]). The mean increments in the mandibular body length were slightly larger in boys than in girls in the present study and in that of Coben. An absence of sex differences in increments of mandibular body length from nine to thirteen years has been reported (Maj and Luzi[9]). The mean distance GO-PO reported by Maj and Luzi for boys and girls combined at nine years was similar to that for the present children at eight years. However, the mean distance AR-GO was much smaller in the present children and the gonial angle was much larger than the means reported by Maj and Luzi. Differences in techniques may be responsible. In the present study, articulare was the point of intersection of the images of the posterior border of the mandible and the inferior border of the basilar part of the occipital bone. Maj and Luzi measured to the "extreme point" of the condyle. Their recorded AR-GO would be larger and their recorded gonial angle would be smaller than those recorded in the present study.

There are reports of larger mean increments in ramal height in girls than in boys (Coben, Maj and Luzi). In the present children, the mean increments were small and were almost the same for each sex. The increment AR-GO (A.L.) was very much larger for boys and girls on Coben's sample than in the present sample indicating that a marked increase in ramus height occurs after eight years.

The proportionate height of the nasal area (N-ANS) was slightly larger in the girls than the boys but N-M was smaller in the girls. The mean proportionate posterior face height (S-GO) and its components (S-AR, AR-GO) were similar in each sex at each age. The posterior face height (S-GO) remained fairly stationary from three to eight years, although a large change occurred in the proportionate anterior face height with a small increase in mean vertical overbite. The mean S-GO measurement in the present girls at eight years is similar to that for girls aged ten years studied by Nanda.

Most mean annual increments from the data of Coben are smaller for girls than boys. This may be due to the sex difference in timing of the circumpuberal spurt in craniofacial growth (Nanda,[8] Bambha and Van Natta[10]). The age interval of the present study would have included a shorter period of reduced rate of growth after puberty in the boys than in the girls.

The mean depth BA-AR did not increase significantly from three to eight years (present study) or from eight to sixteen years (Coben). Consequently, Coben registered serial tracings on BA. In the present study, AR-GO decreased slightly as the ramus became more vertical. There was little mean change in S-PTM and BA-AR.

Large mean increments of growth for GO-PO (A.L.) and AR-GO (A.L.) were observed by Coben in each sex but were slightly larger in the boys. The mean increments for GO-PO (A.L.) in the boys and girls from three to eight years were similar to those reported by Coben. The mean gonial angle decreased similarly in the present children and in those studied by Coben. The

ramus became progressively more vertical and the body of the mandible more horizontal. The height of the anterior cranial base (N-S) showed little change in each sex either from three to eight years (present study) or from eight to sixteen years.

In the present children from three to eight years, there was a larger increment in mean nasal height (N-ANS) than in subnasal height (ANS-M). The girls studied by Coben had similar mean increments for nasal and subnasal heights, but the boys had a slightly smaller mean increment in nasal height than in subnasal height. Meredith reported that nasal height (N-ANS) increased slowly with age in girls. A similar tendency occurred in both boys and girls in the present study. The mean nasal height (N-ANS), expressed as a percentage of total face height (N-M), in the present children closely resembles corresponding proportions that have been reported by Coben,[1] Bergensen,[12] and Meredith.[11]

The largest annual increments (mm) were for GO-PO and N-M in each sex. The mean annual increments draw attention to the rapid increases in mandibular body length and total face height. Posterior face height (S-GO), nasal height (N-ANS) and subnasal height (ANS-M) increased similarly in each sex. The gonial angle and the angle of ramus inclination decreased by 1° annually, the convexity angle decreased slightly, and the facial angle had a slight increase in size.

Before seven years there is rapid growth at the spheno-occipital synchondrosis and the sphenoethmoidal and sphenofrontal sutures. Later, there is little elongation of the anterior cranial base, although there is proliferation of cartilage at the spheno-occipital synchondrosis and ectocranial apposition of bone at nasion.

The horizontal increment observed in BA-S would express growth at the spheno-occipital synchondrosis. Growth in this area has vertical and horizontal vectors; the amount of growth in each direction varies between individuals. Some of the increase in BA-S could be due to apposition at BA.

In the present study there was very little change in S-PTM, measured horizontally. This is in agreement with the finding of Scott.[13] At about three years the mesethmoid unites with the facial parts of the ethmoid and sutural growth ceases in this area. The development and growth of the upper part of the face and the anterior half of the cranial base are closely related. The lack of an increment in S-PTM in the present study would indicate that growth at the sphenoethmoid suture had ceased.

The comparatively large mean increments for PTM-A indicate forward growth of the maxillary complex resulting from growth at the frontomaxillary, the zygomaticomaxillary, the zygomaticotemporal, and the pterygopalatine sutures. In addition, there would be apposition of bone on the posterior surface of the maxilla and on the subnasal part of the maxilla.

In the present study the mean proportionate distance BA-AR has remained almost unchanged during the age range studied indicating that there was some increase in the actual dimension. In the boys and the girls the mean proportionate AR-GO measurement decreased due to the ramus of the mandible becoming more vertical in respect to the Frankfort horizontal plane. Appositional growth on the posterior border of the ramus (Sicher[14]) would have decreased the AR-GO horizontal measurement. This is indicated also by the decrease in the mean ramus inclination angle.

Both the absolute and "projected" measurements of GO-PO had large

mean increments in each sex. This lengthening of the body would be due, in part, to conversion of the former ramus by structural remodeling (Enlow and Harris[15]).

The mean proportionate increment of BA-PO is the total of BA-AR, AR-GO and GO-PO. It is less than that for GO-PO because the mean proportionate measurement AR-GO decreased during the age range studied. The increase in height of the ramus (AR-GO [A.L.]) is due mainly to growth of the condylar cartilage. The mean increment was considerably less than that for GO-PO (A.L.). The mean rate of elongation was larger for the body of the mandible than for the ramus in each sex from three to eight years.

There was a slight increase in the mean mandibular plane angle due to downward and forward movement of pogonion. This could be due to condylar growth and apposition on the inferior border of the symphysis. The height of the anterior segment of the cranial base (N-S) changed only slightly. This could be due to growth at the frontomaxillary and frontonasal sutures resulting in a downward and forward movement of N or a slight superior movement of S. The increase in the proportionate height S-AR would be due to growth at the spheno-occipital synchondrosis. It was similar in each sex during the age range studied. The increase in the mean proportionate height AR-GO would be due to the growth of the condylar cartilage and apposition of bone at GO.

In the present study there were large mean increments in each sex in the total face height. Upper facial height (N-ANS) increased, presumably due to growth at the frontomaxillary, zygomaticomaxillary, zygomaticotemporal and the pterygopalatine sutures resulting in a downward and forward shifting of the maxillary complex. It is interesting to note that the mean increments of N-ANS and S-GO were similar from three to eight years and tended to be slightly larger in the girls (S-GO, boys 6.8 mm, girls 8.0 mm; N-ANS, boys 6.9 mm, girls 7.9 mm).

The mean increment in the ANS-$\underline{1}$ height would be due to apposition at the free border of the alveolar process with the eruption of the teeth (Sicher). The increase in height of the body of the mandible (M-$\bar{1}$) would be due to apposition at the free border of the alveolar process (Sicher). The measurement was made to the incisal edge of the right lower central incisor. Consequently, it would increase with the eruption of this tooth.

The measurement of central incisor overbite was very variable from three to eight years. The deciduous teeth were being replaced by the permanent dentition and each individual exhibited various stages of eruption. The more fully erupted the teeth, the larger the incisor overbite.

The present findings indicate that it is possible to predict the approximate size of many components of the craniofacial skeleton, especially those with a high correlation between levels at different ages in the same individuals. If a child had a total face height (N-M) larger than the mean at three years, it would be reasonable to expect that N-M for this child would be larger than the mean at eight years. Knowledge of the amount of growth in each component from three to eight years is of value in determining whether observed growth is normal. The means and standard deviations allow the extent of abnormality in an individual to be assessed. It should be stressed that the present data were derived from a small sample of children born in Australia to parents of British origin. It would be unreasonable to use them as standards or for pre-

dicting the growth patterns of children of other racial origins.

Orthodontists endeavor to take maximum advantage of the growth potentials of each patient during treatment. From three to eight years, the largest annual increment was in the depth of the body of the mandible. This exceeded all other annual increments except that for total face height. This suggests that between three and eight years would be an appropriate age to arrest the forward growth of the mandible in Class III malocclusion.

Summary

Increments in craniofacial depth and height from age three to eight years have been studied in twenty-six boys and twenty-six girls of British ethnic origin living in Australia. The data were obtained from cephalometric radiographs analyzed by the method of Coben.

The increments in craniofacial depth proportions varied between measurements; the proportionate depth of the middle part of the face (BA-A) increased markedly but the mean depth of the mandibular area (BA-PO) increased only slightly. There were very small proportionate changes in the depths S-PTM and BA-AR. The body of the mandible elongated more than did the ramus. Proportionate changes were reflected in mean decreases in the gonial angle, the convexity angle and the angle of ramus inclination, and mean increases in the facial angle.

There was a large absolute increment in the depth of the body of the mandible (GO-PO) indicating that attempts to control excessive mandibular elongation from three to eight years might be effective.

During the age interval studied, there was a large mean increase in the proportionate anterior face height (N-M) but little change in the proportionate posterior face height (S-GO). The mean proportionate increases in nasal height (N-ANS) were larger than those in subnasal height (ANS-M).

The children studied tended to maintain, from three to eight years, their positions relative to the age means for particular measurements. This indicates that reasonably reliable predictions of craniofacial proportions should be possible.

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References

1. Coben, S. E.: The Integration of Facial Skeletal Variants. *Am. J. Orthodont.*, 41:407-434, 1955.
2. Thompson, D'Arcy W.: *On Growth and Form. New Ed.* Cambridge University Press, 1942.
3. DeCoster, L.: Une nouvelle ligne de référence. *Rev. stomatol.*, 11:937-953, 1951.
4. ———— The Network Method of Orthodontic Diagnosis. *Angle Orthodont.*, 9:3-14, 1939.
5. Roche, A. F. and Sunderland, S.: Melbourne University Child Growth Study. *Med. J. Austr.*, i:559-562, 1959.
6. Downs, W. B.: Variations in Facial Relationships: Their Significance in Treatment and Prognosis. *Am. J. Orthodont.*, 34:812-840, 1948.
7. Scott, J. H.: The Growth of the Human Face. *Proc. Roy. Soc. Med.*, 47:91-100, 1953.
8. Nanda, R. S.: The Rates of Growth of Several Facial Components Measured from Serial Cephalometric Roentgenograms. *Am. J. Orthodont.*, 41:658-673, 1955.
9. Maj, G. and Luzi, C.: Longitudinal Study of Mandibular Growth Between Nine and Thirteen Years as a Basis for an Attempt of Its Prediction. *Angle Orthodont.*, 3:220-230, 1964.
10. Bambha, J. K. and Van Natta, P.: Longitudinal Study of Facial Growth in Relation to Skeletal Maturation During Adolescence. *Am. J. Orthodont.*, 49:481-493, 1963.
11. Meredith, H. V.: Changes in Form of the Head and Face During Childhood. *Growth*, 24: 215-264, 1960.

12. Bergensen, E. O.: The Directions of Facial Growth from Infancy to Adulthood. *Angle Orthodont.*, 36: 18-43, 1966.
13. Scott, J. H.: The Cranial Base. *Am. J. Phys. Anthrop.;* 16:319-348, 1958.
14. Sicher, H.: *Oral Anatomy.* St. Louis, C. V. Mosby Co., 1949.
15. Enlow, D. H. and Harris, D. B.: A Study of the Postnatal Growth of the Human Mandible. *Am. J. Orthodont.*, 50:25-50, 1964.