Late Growth Changes in the Craniofacial Skeleton

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Analysis of serial radiographs shows that growth in the cranial base and in the mandible continues into the third decade. Variations in rate and timing are great, and the total increments after 18 years are usually small.

KEY WORDS: • GROWTH • CRANIAL BASE • MANDIBLE

Little is known of the final phases of craniofacial growth, mainly because of the scarcity of adequate serial records and the small changes at that stage. Scientific interest in the biology of these changes and the need for improved descriptions of them probably outweigh the practical clinical value of such information at the present time.

BEHRENTS (1984, 1985A, 1985B) recently presented analyses of data from the Broadbent-Bolton study (BROADBENT ET AL. 1975), together with a very detailed review of the relevant literature. Consequently, this literature review will be brief and limited to serial studies based on cephalometric radiographs of adults.

It has been previously reported that cranial base lengths did not increase in adults during intervals ranging from 5 to 13 years (CARLSSON ET AL. 1967, CARLSSON AND PERSSON 1967, TALLGREN 1967, 1974).

KENDRICK AND RISINGER (1967) report increases in cranial base lengths during one-year intervals, but almost half of the subjects were younger than 24 years of age at the start of their study.

ISRAEL (1973A, 1973B) reported data from women who were first examined at ages ranging from 24 to 48 years and re-examined 14 to 28 years later. He found significant increases in sella-basion, sella-nasion, gonion-gnathion, and condylion-gnathion, but not in condylion-gonion.

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BEHRENTS (1984, 1985A, 1985B) analyzed data from followup studies of 113 healthy adults who had not received orthodontic treatment. Most early examinations were made at 17 to 19 years, and the later ones at 65 to 83 years. All of the cranial base and mandibular length measurements had increased significantly after 25 and 30 years of age. In addition, there were significant increases in sella-nasion, basion-nasion, and condylion-pogonion after 35 years.

Behrents did not adjust for the effects of multiple comparisons, so the statistical significance of the observed differences is overestimated. None of the increases in mean lengths after the age of 40 years were statistically significant due to the small sample size. While the work of Behrents provides evidence of continuing enlargement in all major dimensions of the cranial base and mandible after 30 years, and enlargement after 35 years for some of these, it does not provide estimates of the ages at which growth in these dimensions ceased.

Estimates of the ages at which growth in specific dimensions ceases require serial data for individuals at multiple ages, rather than paired data from initial and final examinations. Serial data at multiple ages during adulthood were available to Behrents for some subjects, but only the increments from selected ages to the final examinations were analyzed.

A different approach was followed byROCHE ET AL. 1977) who fitted a logistic model to serial cranial base lengths from about 7 to 21 years. They concluded that 95 percent of "adult" size for these lengths was reached at about 15 years in boys and 13 years in girls. The reports of Behrents and of Israel indicate that the final five percent of adult size may be achieved over a long period.

— Material and Methods —

Sets of radiographs were selected from The Fels Longitudinal Study files on the basis of their applicability to analysis of late growth in the craniofacial skeleton. The data presented were obtained from 20 study participants (8 men and 12 women), none of whom had received orthodontic treatment (Fig. 1).

Each participant had a cephalometric radiograph exposed at 17 or 18 years of age, except one man and one woman whose series began at 20 years. From 3 to 8 succeeding radiographs were made of each participant, including at least one between 40 and 50 years of age. Of these radiographs, 41 were taken without a head-holder and 81 were taken with a head-holder. The tube-film distances were recorded for all radiographs, and the positioning was judged to be satisfactory.

One observer traced each radiograph and marked selected cephalometric points. The measurements between these points were made and recorded by another worker using a digitizer with 0.025mm resolution. The craniometric points used were:

Articulare (Ar) — the intersection of the posterior margins of the rami of the mandible with the inferior border of the basisphenoid.

Basion (Ba) — the most posteroinferior point on the anterior margin of the foramen magnum.

Gonion (Go) — the intersection of the mandibular border with the bisector of the angle formed by the projections of the mandibular plane and a line representing the posterior border of the ramus.

Nasion (N) — the most anterior point of the frontonasal suture.

Gnathion (Gn) — the intersection of the anteroinferior margin of the mandibu-

lar symphysis with the bisector of the angle formed by projections of the mandibular plane and a line from nasion tangent to the anterior margin of the symphysis.

Sella (S) — the centroid of sella turcica (the pituitary fossa), determined by inspection.

Measurements (in millimeters) between these points provided data for the lengths of S-N, Ba-N, Ba-S, Ar-Go, Go-Gn and Ar-Gn. The recorded lengths were adjusted for the known radiographic enlargement before further analysis.

— Findings —

Three sets of serial data are shown in Figures 2-4. The data for #001 (Fig. 2) were selected for illustration because this series extended to an older age than any of the others. These data were quite consistent in relation to age with the maximum value for each length occurring at about 32 years, except Go-Gn which peaked at 40 years.

Figure 3 presents the data for participant #072, in whom there were only small changes in these lengths after 17 years, with maximum values at 29 to 38 years.

Figure 4 shows corresponding data for male participant #026. His serial data shows increases in each length from 17 years until 32 years, except Go-Gn and S-N for which the maximum values were reached at 40 years.

Ages at Maximum Values

The age at which a maximum length occurs in an individual is regarded as the age at which growth has ceased. These ages are shown for each length by the arrows in Figures 2-4. They should be interpreted only as indices of the true ages of cessation of growth, which may have occurred at any time between the age at which the immediate preceding radiograph was taken and the age when the maximum value was noted.

The maximum values were reached at mean ages ranging from 29.08 years (Ba-S in women) to 39.25 years (S-N in men) (Table 1). T-tests, adjusting the degrees of freedom for sex-associated differences in the variances when considered necessary, showed no significant difference between the sexes (SNEDECOR AND COCHRAN 1980).

The ages at which the maximum values were reached were not significantly correlated with the ages at peak height velocity (PHV).

Table 1

Distribution Statistics for Ages at which Maximum Value was Reached (years)

Dimension	Men Min	Men Mean	Men Max	Men SD	Women Min	Women Mean	Women Max	Women SD	p
S-N	28.0	39.5	45.9	5.49	29.0	34.9	45.9	4.67	.073
Ba-N	28.0	35.6	47.8	6.53	20.0	33.5	42.5	6.87	.051
Ba-S	28.0	34.8	42.0	4.61	20.0	29.1	46.4	10.73	.054
Ar-Go	28.0	35.3	47.8	6.58	20.0	34.1	47.9	7.28	.700
Go-Gn	28.0	34.3	40.0	4.48	25.5	35.1	47.6	7.11	.748
Ar-Gn	26.0	33.4	41.8	5.21	20.0	35.5	47.9	7.76	.482

None of the sex-associated differences was significant at $p < .05$.

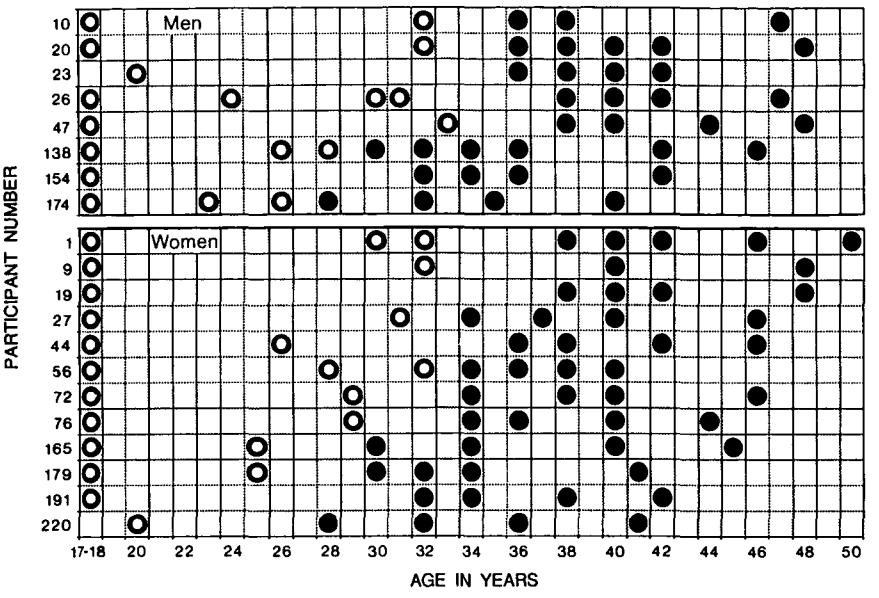

Fig. 1 The ages at which records were available for the 20 study subjects. ○ = head-holder not used ● = head holder used.

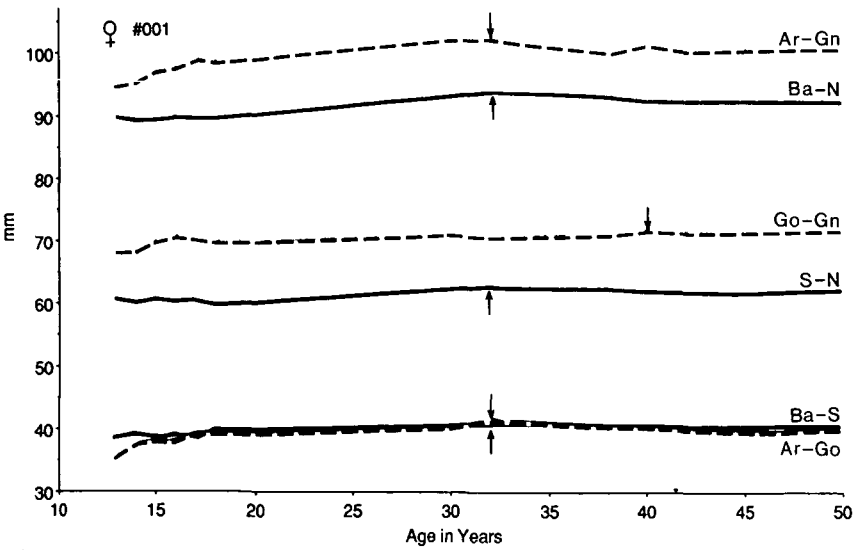

Fig. 2 Data for subject #001, who had an unusually long series. The arrows indicate the maximum values.

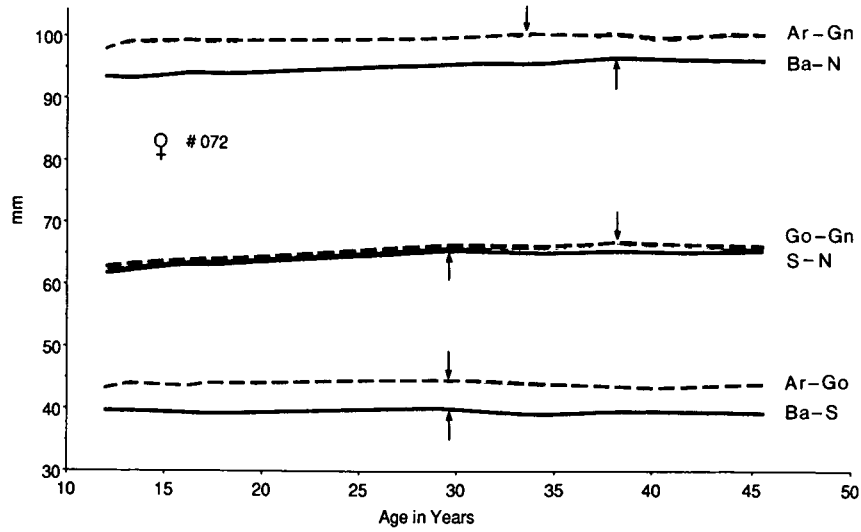

Fig. 3 Serial data for subject #072.
The arrows indicate the maximum values.

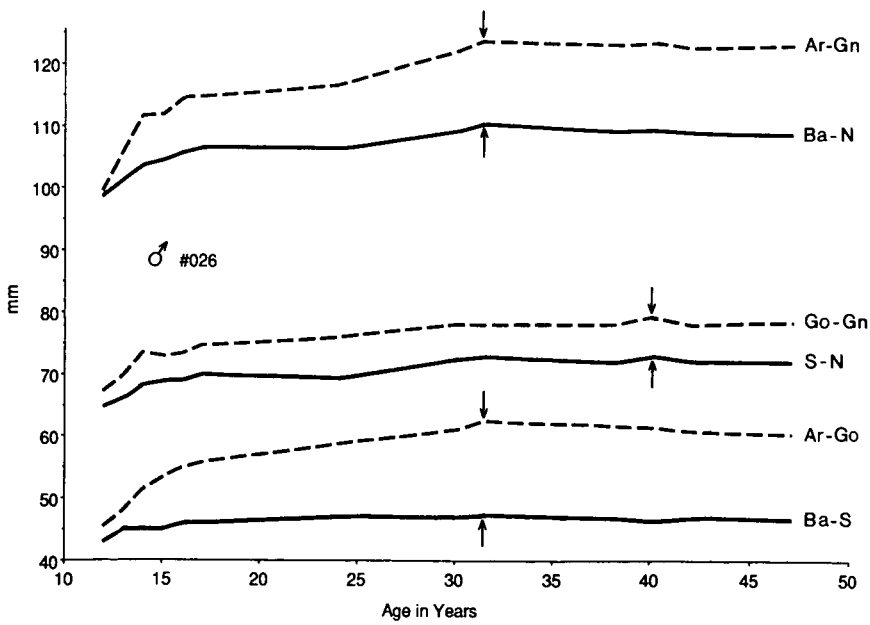

Fig. 4 Serial data for subject #026.
The arrows indicate the maximum values.

Total Increments

The total increments in length from the first record to the maximum values tended to be larger in the men than in the women, particularly for Ar–Go and for Ar–Gn (Table 2). The largest increases were in Ar–Gn, and the smallest in Ba–S.

The total increments in Ar–Go and Ar–Gn were significantly correlated with age at PHV for the combined male and female data ($p < .01$). The corresponding correlations for the other measurements were not statistically significant.

Decrease after Maximum Value

Table 3 presents the differences between the maximum values and the minimum values that were recorded subsequent to attainment of the maximum. With the exception of Ba–N and Ba–S, the mean differences tended to be larger in the men than in the women, but none of the sex-associated differences were statistically significant.

The differences between the maximum values and subsequent minimum values were positively correlated with age at PHV for all dimensions except Ba–S, but the only statistically significant correlation was for S–N ($r = 0.58$; $p < .05$).

Age at Maximum Rate of Growth

The maximum rates of growth (mm/year) were calculated for each dimension

Table 2

Distribution Statistics for Total Increment from 17-18 Years until the Maximum Value was Reached (millimeters)

Dimension	Men				Women			
	Min	Mean	Max	SD	Min	Mean	Max	SD
S–N	1.7	2.7	3.3	0.50	0.5	2.5	4.0	1.10
Ba–N	2.3	3.6	4.8	0.77	1.0	3.0	5.5	1.30
Ba–S	0.1	1.5	3.2	1.16	0.0	1.0	2.2	0.77
Ar–Go	2.5	4.9	6.7	1.51	0.6	1.9	3.3	0.96
Go–Gn	0.5	2.0	4.7	1.45	0.9	2.0	4.6	1.07
Ar–Gn	1.9	5.5	8.8	2.17	1.0	3.0	7.3	1.78

Table 3

Distribution Statistics for the Difference Between the Maximum Value attained and the Subsequent Minimum Value (millimeters)

Dimension	Men				Women			
	Least	Mean	Greatest	SD	Least	Mean	Greatest	SD
S–N	0.2	0.8	1.5	0.48	0.0	0.6	1.7	0.46
Ba–N	0.4	1.0	1.8	0.60	0.0	1.1	2.4	0.81
Ba–S	0.3	0.7	1.6	0.43	0.4	1.1	2.5	0.67
Ar–Go	0.1	1.3	2.1	0.78	0.2	1.2	2.3	0.65
Go–Gn	0.3	0.9	1.9	0.50	0.0	0.7	1.5	0.43
Ar–Gn	0.7	1.3	2.5	0.61	0.0	1.1	2.5	0.83

(Table 4). Because the radiographs were taken at irregular intervals, there were variations in the period for which individual increments were calculated. The mean age at the maximum rate of growth varied from 28.86 years (Ba-N and Ar-Go in the men) to 34.98 years (Ba-S in the women), with large standard deviations (5.16 to 8.58 years).

There was no tendency for different timing of maximum rates of growth in the cranial base and mandible, nor was there a difference between the sexes. There was a negative correlation between age at PHV and the ages at maximum rate of growth in Ba-N and Ar-Go for the two sexes combined ($p < .05$).

Maximum Rates of Growth

The mean maximum rates of growth after 17-18 years were similar for the cranial base and the mandibular lengths. These rates varied from 0.18 mm/year (Ba-S in the women) to 0.43 mm/year (Ar-Gn in the men). The mean maximum rates of growth tended to be more rapid for the men than for the women, but the sex differences were not statistically significant in this small sample (Table 5).

Mean maximum rates of growth for the combined male and female sample were positively correlated with the age of occurrence and age at PHV for each of the dimensions, but these correlations were not statistically significant.

Table 4

Distribution Statistics for the Ages at Maximum Rates of Growth after Age 17 (years)

	Men				Women			
Dimension	Min	Mean	Max	SD	Min	Mean	Max	SD
S–N	24.9	33.3	43.9	7.13	21.8	32.4	43.0	6.98
Ba–N	20.5	28.9	39.0	5.79	21.8	32.8	41.9	6.43
Ba–S	20.5	34.5	41.0	7.34	22.0	35.0	44.0	6.57
Ar–Go	20.5	28.9	37.0	5.79	25.0	33.8	43.0	5.16
Go–Gn	20.5	31.7	41.0	8.10	21.8	34.1	41.9	6.15
Ar–Gn	20.5	29.5	42.8	8.58	21.8	33.0	39.0	5.40

Table 5

Distribution Statistics for the Maximum Rates of Growth after 17-18 Years (mm/year)

	Men				Women			
Dimension	Min	Mean	Max	SD	Min	Mean	Max	SD
S–N	0.1	0.3	0.6	0.17	0.0	0.2	0.5	0.14
Ba–N	0.2	0.4	0.8	0.20	0.1	0.2	0.3	0.09
Ba–S	0.1	0.3	0.7	0.20	0.0	0.2	1.2	0.32
Ar–Go	0.1	0.4	1.0	0.29	0.1	0.3	0.6	0.15
Go–Gn	0.0	0.3	0.6	0.16	0.0	0.2	0.4	0.11
Ar–Gn	0.0	0.4	1.2	0.45	0.0	0.2	0.6	0.15

— Discussion —

The present data are not ideal for the analysis of possible growth in the craniofacial area after 18 years of age. The protocol for a study designed specifically to address this subject should include cephalometric radiographs at regular intervals; two-year intervals from 18 to 50 years would be ideal.

The available data analyzed in the present study were collected at irregular intervals. Despite the imperfect study design, the findings still provide useful information on the timing and the extent of late growth in the craniofacial area.

In the present sample, the maximum values for the cranial base and mandibular lengths within individuals occurred between 29 and 39 years. These ages at identification of maximum values imply that growth ceased sometime between the age at the previous radiograph and 29-39 years. In most cases, the previous radiograph was taken 2-4 years earlier.

This is in general agreement with the findings of BEHRENTS (1984, 1985A, 1985B) and of ISRAEL (1973A, 1973B). Israel reported on data from the Fels Research Institute, but that group did not overlap the present sample.

The present findings are not in agreement with those of CARLSSON ET AL. (1967), CARLSSON AND PERSSON (1967) or with TALLGREN (1967, 1974), who reported that increases in cranial base length did not occur in adults.

In the present study there was a slight tendency for the estimated ages at which growth in cranial base and Ar–Go ceased to be younger in the women than in the men.

The total increments after age 17-18 years were small (means 1.01-5.53 mm), but nevertheless real, because they are markedly greater than the errors of measurement. For the various lengths, the mean interobserver differences ranged from 0.09 to 0.13mm (N=305 radiographs), and the mean intraobserver differences ranged from 0.08 to 0.11mm (N=122 radiographs).

There were small but real *decreases* in the cranial base and mandibular lengths after the maximum values were attained (mean decreases 0.62 to 1.33 mm). The decreases also tended to be larger in the men than in the women.

The maximum rates of growth after 18 years occurred from about 29 to 36 years of age, with marked variations between individuals for particular dimensions. The maximum rates (mm/year) also varied, with standard deviations equal to about 60% of the means for most dimensions. For Ar–Gn in the men, and for Ba–S in the women, the standard deviations were actually slightly greater than the mean increases. The sex-associated differences in the maximum rates were not significant, partly because of the large variances.

The associations between the ages at which the maximum rates of growth in stature occurred during pubescence (PHV) and these aspects of craniofacial growth after 18 years were not close. This would be expected, because these events are separated by intervals of about 15 to 25 years.

There were, however, some significant positive correlations between ages at PHV and the total increments after 18 years, and between PHV and the sizes of the decreases in length that occurred after the maximum lengths had been attained. In addition, there were some significant negative correlations between the ages at PHV and the ages at which the maximum rates of growth occurred.

As noted earlier, the present findings are not definitive. Nevertheless, they do show that growth continues in the cranial base and the mandible into adult life until maximum values are reached in the second and third decades.

The differences between the craniofacial skeleton and the long bones in the timing of the cessation of growth reflect differences in the cellular processes involved in elongation, and in the mechanisms that control its timing.

— Summary —

Serial data from cephalometric radiographs of 20 adults exposed over the age range from 17 to 50 years are analyzed for changes in three cranial base lengths (S-N, Ba-N, Ba-S) and three mandibular lengths (Ar-Go, Go-Gn, Ar-Gn). The recorded dimensions were adjusted for radiographic enlargement before statistical analysis.

The mean ages at which the maximum lengths were identified ranged from 29 to 39 years among the various dimensions. Actual cessation of growth in an individual could have occurred at any time in the 2-4 year interval between this age and the immediately preceding radiograph. This was followed by varying degrees of "negative growth," indicated by successive slightly shorter measurements.

There were small but real increments of growth after 17-18 years, and small but real decreases in length after the maximum values were recorded. The maximum adult growth rate for the six dimensions evaluated occurred at mean ages between 29 and 35 years, with highly variable individual timing and rates of growth.

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