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SCIENTIFIC SECTION

Quantification of cranial base growth during pubertal growth

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Objective: To quantify longitudinal cranial base growth from prepubertal through postpubertal stages of development, as defined by biological indicators of individual skeletal maturity (cervical vertebral maturation – CVM) method and to determine if there is sexual dimorphism resulting from cranial base growth.

Design: A longitudinal cephalometric study.

Setting: The Dental School of Paulista University, Brazil.

Participants: 36 subjects (21 females, 15 males) who were part of a longitudinal growth study and exhibited normal facial and normal vertical growth patterns.

Methods: Growth maturation of cervical vertebrae stages was assessed by two examiners independently. Cranial base measurements were carried out by one individual and repeated after one month. The growth increments over time were assessed with the one-way repeated-measures analysis of variance and post hoc Tukey multiple comparisions.

Results: There were no significant gender differences. There was a significant increase in all cephalometric measures between the different time points. Ba–Na showed the greatest amount of growth (mean change=2.8 mm). From T2–T3, the greatest amount of growth was found for Se–Na (mean change=3.4 mm) and the lowest for CC–Na (mean change=1.4 mm). Comparing overall changes (T1–T3) all the measurements showed statistically significantly increases ($P<0.05$). For all comparisons of between-stage changes the cranial base grew more than 2.0 mm during the pubertal growth.

Conclusions: Linear variables of cranial base showed significant growth during pubertal stages (pre-peak, peak and post-peak). No significant differences.

Key words: Cranial base, anterior cranial base, posterior cranial base, cephalometric, cervical vertebrae, pubertal growth

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Introduction

Knowledge and understanding of craniofacial growth and development during puberty are important for diagnosis, treatment planning, evaluation of treatment results and stability.[1,2]

The cranial base is the template for facial development; therefore it is directly related to growth and displacement of both the maxilla and mandible. Understanding the normal pattern of cranial base development helps in the recognition of abnormalities of craniofacial growth.[3–7] Growth of the cranial base occurs by means of a complex balance including enlargement of the frontal sinuses, surface remodelling in the nasion region and interstitial growth at the spheno-occipital synchondrosis.[8–12]

The aim of this study was to quantify cranial base growth from prepubertal through postpubertal stages of development, as defined by the biological indicator of individual skeletal maturity [cervical vertebral maturation (CVM) method] and to determine if there are any differences in cranial base growth between genders.

Subjects and methods

The subjects for this study were identified from individuals who took part in a longitudinal growth study at the Dental School of Paulista University, Brazil. The growth study involved 150 orthodontically untreated subjects with either a Class I or a Class II malocclusion who had longitudinal records collected

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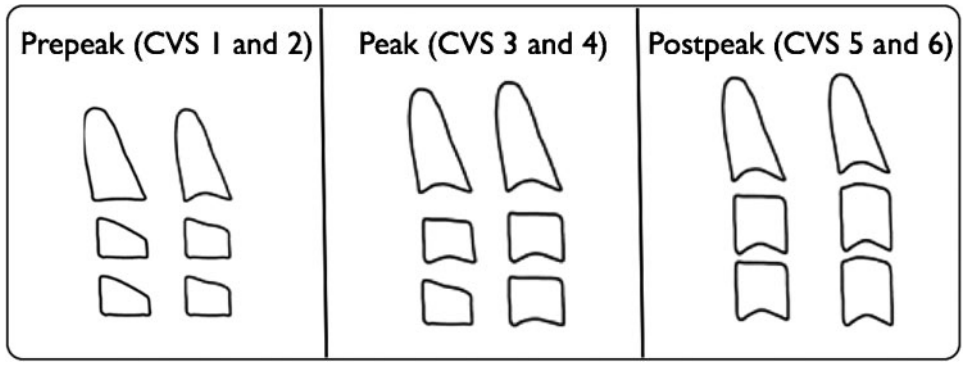

Figure 1 Diagrammatic representation of CVM stages. CS1 and CS2 are prepubertal stages. CS3 and CS4 comprise the pubertal growth spurt. CS5 and CS6 are postpubertal stages. Stage assessment is based on visual analysis of cervical vertebrae on lateral cephalograms

from childhood to adulthood time. Ethical approval was obtained from a Brazilian Health Sciences Institutional Review Board (ref. CAAE - 1.0.251/2006).

The criteria for including the radiograph in this study were:

1. Class I anteroposterior relationship (ANB 2–4°);
2. Average skeletal vertical relationships (Gonial angle=130±7°, CoGoMe=124±4°);
3. Normal overbite and overjet;
4. No significant or adverse medical history.

Of the 65 individuals in the wider growth study who fulfilled the inclusion criteria, 20 did not have radiographs corresponding to the age of interest or the radiographs were missing and nine were excluded due to poor quality lateral cephalometric radiographs. Therefore, the sample consisted of 36 subjects (15 male, 21 female). The average age at the first radiograph was 10.4 years (SD 0.98).

The CVM stage of each radiograph was assessed according to the method described by Baccetti *et al.*[13] (Figure 1). The radiographs of each subject were divided into T1 pre-peak (CS1 and CS2), T2 peak (CS3 and CS4) and T3 post-peak (CS5 and CS6) groups. Two examiners (L.A.M. and C.L.F.O.) evaluated the cervical stage (CS) independently and agreed on the final categorization. The reliability of the visual assessment was determined using a kappa statistic. The T1, T2 and T3 lateral cephalograms were hand traced by one investigator (L.A.M.), and landmark locations, anatomical contours, and tracing superimpositions were verified by a second examiner (C.L.F.O.). Disagreements were resolved to the satisfaction of both investigators. All measurements were repeated one month later by one operator (L.A.M).

The cephalometric landmarks identified were (Figure 2):

1. Basion (Ba): the most posteroinferior point on the anterior margin of foramen magnum;
2. Nasion (Na): the most anterior point of the frontonasal suture;
3. Sela (Se): the centroid of sella turcica (pituitary fossa) determined by inspection;
4. Porion (Po): the uppermost point of the external auditory meatus;
5. Gnathion (Gn): the most inferior anterior point on the contour of the bony chin symphysis;
6. Centre of the cranium (CC): the landmark at the intersection of the Ba–Na and Pt–Gn lines;
7. Frankfort Centre (CF): the intersection between the Frankfort horizontal plane and a vertical line touching the distal margin of the pterygomaxillary fissure.

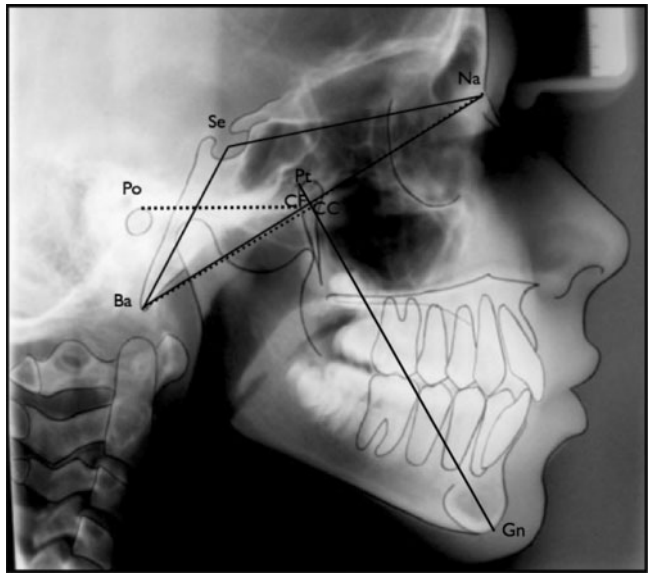

Figure 2 Cephalometric landmarks used in this study

Table 1 Reproducibility measurements (reading 1 v reading 2) mean difference, standard deviation, 95% confidence interval of differences, *P* value (paired *t* test) and intra-class correlation coefficient

Reading	Mean difference	SD	Lower 95% CI	Upper 95% CI	*P*	ICC
Ba–Na	−0.10	0.24	−0.18	−0.02	0.018	0.998
Se–Na	−0.22	0.64	−0.43	−0.00	0.049	0.961
CC–Na	−0.04	0.24	−0.12	0.04	0.343	0.997
Se–Ba	−0.36	0.98	−0.69	−0.03	0.034	0.946
CC–Ba	−0.08	0.26	−0.17	0.00	0.062	0.995
CF–Po	−0.07	0.20	−0.14	−0.00	0.041	0.998

Measurements (in millimetres) were carried out between the following landmarks Ba–Na, Se–Ba, Se–Na, CC–Na, CC–Ba, CF–Po and were adjusted for the known radiographic enlargement before further analysis.

Statistical analysis

The method error was assessed using a paired *t*-test for systematic error and the intra-class correlation coefficient to estimate random error. Descriptive statistics were computed for all variables at T1, T2 and T3. The differences between the growth increments over time and between males and females were assessed with the one-way repeated-measures analysis of variance. Post hoc multiple comparisions were carried out with the Tukey multiple-comparison tests. The significance level was set at $P<0.05$.

Results

The interobserver examinations for the cervical staging showed very good agreement (kappa=0.92).[14] The reproducibility data are shown in Table 1. Four of the six measurements showed evidence of systematic error ($p=0.10$), but the mean differences were small and all the intra-class correlation coefficients were found to be greater than 0.95, therefore the error was considered acceptable.

The mean ages of the participants at each time are given in Table 2. The mean values, standard deviations and confidence intervals for each variable are given in Tables 3–8.

The ANOVA table is shown in Table 9. There were no significant differences between genders for any of the cephalometric measures ($P>0.05$), therefore the male and female data at each time point were pooled. The results of the Tukey multiple-comparison tests between the different time points for each radiograph are shown in Table 10. The study group showed statistically significant differences between T1–T2, T2–T3 and T1–T3.

From T1–T2, all cephalometric measures were significantly different. Ba–Na showed the greatest amount of growth (mean change=2.8 mm; $P<0.001$). From T2–T3, again the differences were significant for all cephalometric measures ($P<0.001$). The greatest amount of growth was found for Se–Na (mean change=3.4 mm) and the lowest for CC–Na (mean change=1.4 mm), both of which indicate anterior cranial base growth (Tables 3 and 4).

Comparing overall changes (T1–T3) all the measurements showed statistically significantly increases

Table 2 Mean age (standard deviation) in years at each time point

	Mean age (standard deviation) in years	
Time	Male ($n=15$)	Female ($n=21$)
T1	10.2 (1.2)	9.4 (0.7)
T2	13.3 (2.5)	11.5 (3.3)
T3	16.2 (3.3)	15.2 (3.7)

Table 3 Mean values, standard deviations and confidence intervals for Ba–Na

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	Ba–Na T1	97.81	5.17	95.46	100.17
		Ba–Na T2	100.15	5.27	97.76	102.55
		Ba–Na T3	102.39	5.64	99.82	104.96
Male	15	Ba–Na T1	98.33	3.09	96.62	100.05
		Ba–Na T2	101.83	3.43	99.93	103.73
		Ba–Na T3	104.04	3.57	102.07	106.01

Table 4 Mean values, standard deviations and confidence intervals for Se–Na

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	Se–Na T1	65.51	1.86	64.67	66.36
		Se–Na T2	67.52	1.95	66.64	68.41
		Se–Na T3	71.00	2.22	69.98	72.01
Male	15	Se–Na T1	65.89	2.79	64.34	67.43
		Se–Na T2	68.53	2.98	66.89	70.18
		Se–Na T3	70.45	2.99	68.80	72.11

Table 5 Mean values, standard deviations and confidence intervals for CC–Na

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	CC–Na T1	50.45	3.13	49.02	51.87
		CC–Na T2	52.49	2.42	51.39	53.59
		CC–Na T3	54.06	2.92	52.73	55.39
Male	15	CC–Na T1	50.95	2.73	49.44	52.46
		CC–Na T2	53.43	2.56	52.01	54.84
		CC–Na T3	54.40	2.90	52.79	56.01

Table 6 Mean values, standard deviations and confidence intervals for Se–Ba

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	Se–Ba T1	42.88	3.19	41.43	44.33
		Se–Ba T2	45.02	2.64	43.82	46.22
		Se–Ba T3	46.58	3.10	45.17	47.99
Male	15	Se–Ba T1	43.88	2.55	42.47	45.29
		Se–Ba T2	45.87	2.43	44.52	47.21
		Se–Ba T3	47.45	2.18	46.24	48.65

Table 7 Mean values, standard deviations and confidence intervals for CC–Ba

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	CC–Ba T1	46.34	2.78	45.07	47.61
		CC–Ba T2	48.56	2.59	47.38	49.74
		CC–Ba T3	50.98	2.50	49.84	52.12
Male	15	CC–Ba T1	47.40	2.52	46.01	48.79
		CC–Ba T2	49.07	2.13	47.89	50.25
		CC–Ba T3	51.03	2.52	49.64	52.43

Table 8 Mean values, standard deviations and confidence intervals for CF–Po

Gender	*n*	Variable	Mean	SD	Lower 95% CI	Upper 95% CI
Female	21	CF–Po T1	38.94	3.22	37.48	40.41
		CF–Po T2	40.35	3.71	38.66	42.03
		CF–Po T3	41.73	3.22	40.27	43.20
Male	15	CF–Po T1	39.28	3.57	37.30	41.26
		CF–Po T2	41.99	2.68	40.51	43.48
		CF–Po T3	43.76	3.30	41.93	45.59

($P<0.05$). The measurements showing the greatest amount of growth during this study period were Ba–Na (mean change=5.0 mm) and Se–Na (mean change=5.1 mm).

For all comparisons of between-stage changes (T1–T2, T2–T3 and T1–T3) the cranial base grew more than 2.0 mm during the pubertal growth. The period of time displaying the higher growth was between T1–T2.

Discussion

This study has used a longitudinal sample to show important cranial base growth during puberty. The cranial base plays a key role in craniofacial growth, helping to integrate, spatially and functionally different patterns of growth in various adjoining regions of the skull, such as components of the brain, nasal cavity, oral cavity and pharynx. There is also a relationship between the cranial base variations and sagittal malpositions of the jaws.[15,16] Thus, the knowledge of cranial face growth is important in the understanding of craniofacial development.

No previous investigation has studied the longitudinal effects of cranial base growth during pubertal growth using the CVM method as a biological indicator of individual skeletal maturity. In order to provide this important information, the present study analyzed changes of cranial base during a mean period of 6 years follow-up. These data demonstrate that cranial base growth occurs until adulthood.

Total length of cranial base

The total length of the cranial base, represented by Ba–Na measurement, increased during all the periods examined, confirming that the cranial base grows during all the pubertal phases. According to our results, this growth is largest during the interval between the pre-peak stage and the peak of pubertal growth, decreasing in the post-peak period.

Similar results were shown by Lewis *et al.*[1,17,18] who studied cranial base lengths and demonstrated pubertal growth for Ba–Na in both male and female subjects. Roche *et al.*[19] continued their study of basal growth through adolescence to at least 21 years and found that the cranial base elongates more in the male group throughout this period, not necessarily at a greater rate, but for a longer period of time. In addition, they noted that 95% of the mature length of cranial base was reached around 11 to 13 years old in the female group and 15 years in the male group.

Anterior cranial base

The anterior cranial base was represented by Se–Na and CC–Na measurements. Both increased during the periods examined. Melsen[20] states that the growth of the spheno-ethmoidal and sphenofrontal suture usually terminates at 7 years old. Anterior cranial base growth is

Table 9 Results of the one-way repeated-measures analysis of variance with dependent measurement of craniofacial measurements and independent variables of gender and time point when radiograph was taken ($n=36$)

Reading	Variable	d.f.	*F*	*P*
	Gender	1	1.10	0.302
Se–Ba	Time	2	60.72	<0.001
	Time*Gender	2	0.03	0.971
	Gender	1	0.13	0.719
Se–Na	Time	2	196.92	<0.001
	Time*Gender	2	3.28	0.050
	Gender	1	0.71	0.405
Ba–Na	Time	2	80.60	<0.001
	Time*Gender	2	1.47	0.246
	Gender	1	0.44	0.511
CC–Ba	Time	2	136.71	<0.001
	Time*Gender	2	2.14	0.133
	Gender	1	0.47	0.498
CC–Na	Time	2	37.96	<0.001
	Time*Gender	2	0.89	0.422
	Gender	1	1.66	0.207
CF–PO	Time	2	31.92	<0.001
	Time*Gender	2	2.13	0.135

Table 10 Results of the Tukey multiple-comparison tests ($n=36$)

Variable	Comparison	*F*	*P*
	T1–T2	40.19	<0.001
Se–Ba	T1–T3	121.95	<0.001
	T2–T3	37.08	<0.001
	T1–T2	178.49	<0.001
Se–Na	T1–T3	342.60	<0.001
	T2–T3	97.77	<0.001
	T1–T2	74.86	<0.001
Ba–Na	T1–T3	165.05	<0.001
	T2–T3	63.76	<0.001
	T1–T2	106.55	<0.001
CC–Ba	T1–T3	270.96	<0.001
	T2–T3	85.29	<0.001
	T1–T2	43.48	<0.001
CC–Na	T1–T3	77.60	<0.001
	T2–T3	27.98	<0.001
	T1–T2	39.96	<0.001
CF–PO	T1–T3	65.44	<0.001
	T2–T3	26.55	<0.001

still necessary after the brain has virtually ceased to grow at 7 to 8 years old to enable facial growth to occur. This growth takes place almost entirely by increased pneumatization of frontal and ethmoid bones, so further increases in Se–Na are mainly contributed by growth of the frontal bone.[21,22]

The increase in thickness of Na from birth to adulthood is accounted for by enlargement of the frontal sinus.[22,23] Rapid growth of the sinuses continues until 12 years old, when they reach nearly adult size.[24] This finding was supported by Brown *et al.*,[25] who showed that the median age at which the main increase in size of the sinus ceased was 15.7 years for boys and 13.7 years for girls, thus suggesting that the enlargement of the frontal sinus, a mainly osteoclastic activity, follows the trends for growth in bone lengths very closely. Hence, this might explain why all cephalometric measures from this study involving Nasion increased during puberty.

According to Enlow and Hans[26] the nasomaxillary complex, suspended by sutures from the anterior cranial base and the frontal lobes, is carried anteriorly as the combined frontal and temporal lobes progressively expand. Melsen and Ousterhout[27] related that the maxillary bones are connected to the surrounding bones by the circummaxillary sutures that include the zygomaticomaxillary, frontomaxillary, pterygomaxillary and the median palatal sutures. These sutures allow the displacement, as well as growth of the maxilla; however, the sutures start to interlock after the pubertal growth spurt and are difficult to separate using orthopedic forces.

The results of this study showed the greatest amount of growth in the anterior cranial base. Hence, Class III malocclusion treatment directed at the maxilla may be more effective if started during the pubertal growth period, because of the anterior growth of the anterior cranial base and related forward displacement of maxilla.

Posterior cranial base

The posterior cranial base was represented by three different measures (Se–Ba, CC–Ba and CF–Po) and during all different studied periods, there were significant differences. All the posterior measurements showed almost the same proportional growth increases when the changes T1–T3 were analyzed.

Thilander and Ingervall[28] performed histological and microradiographic studies based on autopsy material. According to their study, the increase in Se–Ba length is described primarily to growth activity at the spheno-occipital synchondrosis. Frik *et al.*[29] reported a wide variation in the time of fusion of the spheno-occipital synchondrosis. Recently, Sahni *et al.*[30] showed that in the males, partial fusion was seen at 13 years old while complete fusion was noticed at 15 years old in 25% of the subjects, therefore the age at which the majority of boys have complete fusion was 15 years old or above. In females, the earliest partial fusion was noted at 12 years old and complete fusion was present at 13 years old in 16.6% with all female subjects showing complete fusion at 17 years old. Kahana *et al.*[31] however, found no correlation between the chronological age and the time of closure of the synchondrosis. Thus, during the age range in our study, the synchondrosis is likely to be still open, but close to closure and termination of growth in most of subjects.

Mitani[32] and Kasai *et al.*[12] showed that cranial base growth is dependent on the brain growth during infancy and in puberty growth is related to general body growth. However, for the posterior cranial base, growth varies during life.

There is some overlap between the midline and lateral structures in the cranial base. Measurements in three dimensions (volume) would be more accurate than those in two dimensions (area). CBCT data sets can provide undistorted 3D morphology, making it possible to identify craniofacial structures more naturally. However, landmark identification in 3D is not simple. No such three-dimensional longitudinal growth data are available.

Gender differences

The present study, unlike other studies,[9,17,19,33] showed no statistically significant differences between the genders for any of the measurements. This may have been due to the sample size. A power calculation using the data from this study suggests that for Ba–Na and Se–Ba measurements we would require a sample size of 92 for Ba–Na and 130 to Se–Ba, in each gender, to detect a significant difference at the $P>0.05$ with a power of 0.85.

Conclusions

This study found the following:

- Linear measurements of cranial base length showed significant growth during all pubertal stages (pre-peak, peak and post-peak stages).
- No significant differences were found between genders in any cephalometric measures during the pubertal stages.

Contributors

Luciana Malta was responsible for study design; obtaining funding; logistic, administrative, and technical support and data interpretation; drafting, critical revision, and final approval of the article. Cristina Ortolani was responsible for recruitment of participants and data collection; analysis; and drafting, critical revision, and final approval of the article. Kurt Faltin is the guarantor.

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