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Longitudinal cephalometric standards for the neurocranium in Norwegians from 6 to 21 years of age

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SUMMARY The purpose of this study was to establish and describe normative cephalometric standards of the neurocranium (theca cranii and cranial base) for Norwegian males and females from 6 to 21 years of age using lateral cephalograms.

The subjects included 35 males and 37 females from the Oslo University Growth Archive with lateral cephalograms taken every third year from 6 to 21 years of age. The total number of lateral cephalograms was 194 from males and 200 from females. All subjects were Caucasian, all had normal occlusion and no apparent facial disharmony, and none had undergone orthodontic therapy. Nineteen measurements and three indices of the neurocranium were analysed longitudinally. Comparisons between the various parameters in the neurocranium of males and females in each age group were performed using the Student's *t*-test.

The size of the neurocranium of females was smaller than that of males throughout the observation period and the differences increased with age, particularly the diameter of the neurocranium (n–l), length of the neurocranium (n–opc), anterior cranial base length (n–s), and posterior cranial base length (s–ba).

The cephalometric standards of the neurocranium established in this study can be used as a reference material in investigations of individuals with various craniofacial aberrations and syndromes.

Introduction

Normative cephalometric data are important as reference standards in orthodontic diagnosis. Such normative data need to be standardized for age, sex, and ethnic group, as these factors influence cranial morphology. Results from several normative data studies from different parts of the world have been published and used as reference material in orthodontic research. These include the Michigan (Riolo *et al.*, 1974), Bolton (Broadbent *et al.*, 1975), Nijmegen (Prahl-Andersen *et al.*, 1979), and King's Growth Studies (Bhatia and Leighton, 1993). Furthermore, growth studies have been collected in university projects to develop standards for specific ethnic groups (Alexander and Hitchcock, 1978; Engel and Spolter, 1981; Munandar and Snow, 1995). Several investigators have demonstrated that ethnic groups vary in their dentofacial relationships (Johnson *et al.*, 1978; Björk *et al.*, 1984; Trenouth *et al.*, 1985, 1999).

Many studies have shown that linear and angular cephalometric measurements of the face and cranial base differ between males and females, and also change with age (e.g. Riolo *et al.*, 1974; Broadbent *et al.*, 1975; El-Batouti *et al.*, 1995).

Differences have been demonstrated in cephalometric values among Scandinavians by Solow and Sarnäs (1982), who compared Swedish and Danish adults, and by Thilander *et al.* (1982), who compared three Swedish studies with one Norwegian study (Humerfelt, 1970).

Normative craniofacial data from a longitudinal dentofacial cephalometric analysis of a Norwegian population, aged 6–18 years, have been published (El-Batouti *et al.*, 1994).

Cephalometric standards for the neurocranium and face evaluated from a Danish adult male sample (Kisling, 1966; Solow, 1966) and a Danish adult female sample (Ingerslev and Solow, 1975) have been used as reference standards in the study of various craniofacial syndromes, e.g. Down syndrome (Kisling, 1966), cleidocranial dysplasia (Jensen, 1994), and Apert syndrome (Kreiborg *et al.*, 1999).

There is a growing interest in the study of human neurocranial dysmorphology, but only a few cephalometric standards are available on normal neurocranial development. Normal standards are essential for describing the abnormal morphology of the head in various syndromes.

The purpose of this study was to describe and establish normative lateral cephalometric standards of the neurocranium in Norwegian males and females from 6 to 21 years of age. Longitudinal normative data on neurocranial morphology can be useful in the scientific evaluation of abnormal neurocranial development in different craniofacial abnormalities.

Materials and methods

Study population

The data were derived from serial lateral cephalograms from the Oslo University Growth Archive. The archive was collected between 1972 and 1992. Children from the county of Nittedal outside Oslo, born in the period 1958 to 1972, were invited to a dental examination including dental study casts, panoramic radiographs, lateral radiographic cephalograms, and facial photographs at 6, 9, 12, 15, 18, and 21 years of age. No measurements of total body height or head circumference were taken. The total number of individuals in the project was 4229, although the number of individuals with longitudinal registrations from 6 to 21 years was small.

The present material comprised 72 individuals (35 males and 37 females) who had lateral cephalograms taken every third year from 6 to 18 years of age. In addition, lateral cephalograms were available for 34 of the same subjects (19 males and 15 females) at 21 years of age. The total number of cephalograms was 394 (194 male and 200 female). Age distribution for both sexes is presented in Table 1.

All participants were Norwegian Caucasians with a normal occlusion in the sagittal, transverse, and vertical dimension, with only minor deviations in the form of rotations and/or spacing (less than 1 mm) at the age of 18 years, and no apparent facial disharmony. None of the participants had undergone orthodontic treatment.

Longitudinal dentofacial cephalometric data from the same sample have previously been presented (El-Batouti *et al.*, 1994). Of the 39 female subjects described in that investigation two subjects were excluded from the present study; one due to surgery in the posterior part of the cranial vault and cranial base at the age of 18 years, and the other due to extraction of a maxillary premolar and subsequent minor orthodontic treatment at the age of 17 years.

Cephalometric methods

The lateral radiographs were taken in the same Lumex B (Siemens) cephalostat. The distance from the focus to the median plane was 180 cm and the median plane–film distance was 10 cm, giving an enlargement of the midline structures of 5.6 per cent. The radiographs were taken with the subjects seated, the head fixed in the cephalostat with ear-rods and support on the forehead, the teeth in the maximum intercuspal position, the lips sealed in a relaxed position, and the Frankfort plane parallel to the floor. The results were corrected for the enlargement factor.

Cephalometric analyses

The definition of the reference points is in accordance with Björk (1960) and Solow (1966). The following cephalometric reference points were identified on each radiograph (Figure 1):

basion (ba), the most postero-inferior point on the clivus; bregma (br), the intersection between the sagittal and coronal sutures on the surface of the cranial vault;
frontale (f), a point on the surface of the frontal bone determined by a perpendicular to the line joining the nasion and bregma and passing through its mid-point;
lambda (l), the intersection between the lambdoid and sagittal sutures on the surface of the cranial vault;
nasion (n), the most anterior point on the fronto-nasal suture;
opisthocranion (opc), the most posterior point on the surface of the cranial vault defined as the point farthest from the nasion (disregarding the external occipital protuberance);
sella turcica (s), the centre of sella turcica. The upper limit of the sella turcica is defined as the line joining the tuberculum and dorsum sellae.

Table 1 Subject characteristics.

		Number	Mean age	SD	Min	Max
Male	6 year group	35	6.0	0.3	5.4	6.7
	9 year group	35	8.9	0.4	8.3	9.7
	12 year group	35	11.9	0.4	11.3	12.7
	15 year group	35	14.9	0.4	14.3	16.0
	18 year group	35	18.2	0.4	17.4	18.8
	21 year group	19	21.3	0.4	20.5	22.2
Female	6 year group	37	6.0	0.4	5.1	6.7
	9 year group	37	8.9	0.4	8.1	9.6
	12 year group	37	11.9	0.4	11.1	12.7
	15 year group	37	14.9	0.4	14.1	15.7
	18 year group	37	18.1	0.4	17.3	18.9
	21 year group	15	21.3	0.6	20.4	22.4

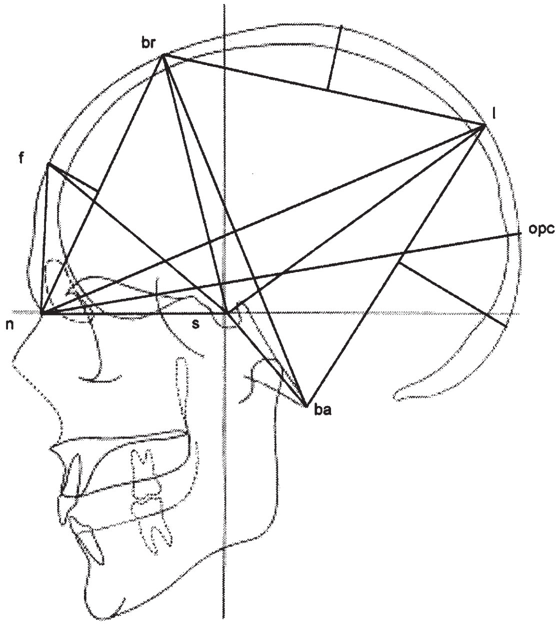


Figure 1 Reference points and cephalometric variables. Angular measurements (degrees): s–n–f, prominence of the frontal bone; n–s–ba, cranial base angle. Linear measurements (mm): s–n, anterior cranial base length; s–ba, posterior cranial base length; s–f, distance from sella to the frontal bone; n–br, distance from nasion to bregma; s–br, distance from sella to bregma; ba–br, distance from basion to bregma; br–l, distance from bregma to lambda; s–l, distance from sella to lambda; n–l, distance from nasion to lambda; n–opc, diameter of the neurocranium from nasion to opisthocranion; ba–l, distance from basion to lambda. The maximum distances from the cords nasion–bregma, bregma–lambda, and lambda–basion to the corresponding arch segments: n–br to the frontal bone; br–l to the parietal bone; l–ba to the occipital bone. The thickness of the frontal, parietal, and occipital bones were defined as the distances from the points where the perpendicular bisectors of the cords nasion–bregma, bregma–lambda, and lambda–basion intersected the inner and outer contours of the respective bones: thickness of the frontal bone; thickness of the parietal bone; thickness of the occipital bone. Definitions of the reference points according to Björk (1960) and Solow (1966). Definitions of the variables according to Solow (1966) and Kisling (1966).

The definitions of the calculated variables are shown in Figure 1. All reference points used were situated in the midsagittal plane.

The reference points were digitized and processed using a computer program (Dentofacial Software Inc., Toronto, Ontario, Canada). The magnification of the linear measurements was corrected by the program. The measurements were calculated to the nearest 0.1 mm or 0.1 degrees.

Measurements of the curvature of the frontal, parietal, and occipital bones, respectively, were provided by the relationship between the greatest perpendicular distance to the surface of the cranial vault and the length of the cords using the curvature index defined by Young (1956). The higher the index the greater the curvature of the bone surface.

Assessing the method errors

Twenty radiographs chosen at random were traced and digitized by one author (SA) on two separate occasions at least two weeks apart. Measurement errors were estimated according to Dahlberg (1940). The coefficient of reliability and the variance of the duplicate measurements were also calculated, as recommended by Houston (1983).

The error of duplicate measurements was generally small. The range for linear measurements was 0.1 to 0.6 mm, and the angular measurement 0.1 to 0.6 degrees. The largest variation found for angular measurements was the cranial base angle (n–s–ba), and for linear variables the thickness of the frontal and parietal bones. The results from the error study are given in Table 2.

Statistical analyses

The statistical differences between the arithmetic means of all measurements in the male and female age groups were compared using the Student's *t*-test for independent data.

Missing variables

It was not possible to identify the reference point bregma (br) on some of the radiographs, particularly in the older male groups, because the head was too large to fit the format of the radiographic cassette. In those cases the reference point bregma was situated on the edge of or just outside the radiograph. The following variables were affected by the missing reference point: s–n–f, ba–br, s–f, s–br, n–br, br–l, cord n–br to the frontal bone, cord br–l to the parietal bone, thickness of the frontal bone, and thickness of the parietal bone. The number of valid measurements in all variables is noted in Tables 3–9.

Results

Data for the cephalometric measurements of the neurocranium for males and females at 6, 9, 12, 15, 18, and 21 years with arithmetic mean, standard deviations, maximum and minimum values, and level of statistical significance between males and females are presented in Tables 3–8, respectively. The variables are also graphically illustrated in Figures 2–7. The calculated curvature indices for the frontal, parietal, and occipital bones, respectively, are shown in Table 9.

The values of the change in various parameters differed during the observation period, and between the male and female groups. In general, most of the changes in the various parameters in females occurred between the ages of 6 and 15 years, while in the male group these were between 6 and 18 years. Males consistently showed larger values for most linear variables.

Table 2 Error of the method.

Variables	Dahlberg's calculation	Houston's coefficient of reliability (%)	Variance of the difference between duplicate measurements
Angular measurements (degrees)			
s–n–f	0.20	99.94	0.03
n–s–ba	0.24	98.56	0.02
Linear measurements (mm)			
s–n	0.13	99.32	0.01
s–ba	0.16	98.78	0.02
s–f	0.15	97.21	0.02
n–br	0.13	99.37	0.01
s–br	0.14	97.17	0.01
ba–br	0.15	98.18	0.02
br–l	0.09	99.28	0.01
s–l	0.16	99.73	0.02
n–l	0.13	99.62	0.01
n–opc	0.17	99.72	0.01
ba–l	0.12	99.53	0.01
n–br to the frontal bone	0.18	97.30	0.02
br–l to the parietal bone	0.18	97.60	0.02
l–ba to the occipital bone	0.12	99.40	0.01
Thickness of the frontal bone	0.19	96.81	0.03
Thickness of the parietal bone	0.22	97.45	0.05
Thickness of the occipital bone	0.16	97.39	0.04

Table 3 Cephalometric standards for males and females at 6 years of age.

		Male (*N* = 35)					Female (*N* = 37)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	93.4	2.8	87.1	99.7	35	94.3	3.5	88.0	101.7	37	n.s.
n–s–ba	deg	130.8	4.7	120.4	141.4	35	130.8	4.7	121.6	138.0	37	n.s.
s–n	mm	61.7	2.2	57.8	68.5	35	60.8	1.8	57.3	65.5	37	n.s.
s–ba	mm	37.4	2.4	32.7	41.5	35	36.7	2.3	32.0	41.1	37	n.s.
s–f	mm	88.1	4.2	81.5	97.3	35	87.2	3.3	82.2	96.4	37	n.s.
n–br	mm	105.5	3.9	99.4	113.4	35	103.5	4.9	94.0	115.0	37	n.s.
s–br	mm	98.9	3.7	94.4	105.5	35	97.2	4.3	92.1	108.1	37	n.s.
ba–br	mm	132.0	4.2	123.5	139.7	35	129.3	3.9	122.9	139.8	37	**
br–l	mm	123.2	5.2	109.8	131.3	35	119.6	6.2	109.6	136.4	37	*
s–l	mm	113.9	5.3	102.7	122.4	35	111.4	6.2	99.4	127.6	37	n.s.
n–l	mm	169.4	5.2	159.9	181.2	35	165.7	6.5	152.6	180.4	37	*
n–opc	mm	170.9	5.2	161.7	182.1	35	167.3	7.2	152.3	183.1	37	*
ba–l	mm	113.2	4.9	100.1	124.3	35	110.9	5.2	99.8	124.7	37	n.s.
n–br to the frontal bone	mm	26.6	2.2	22.2	32.6	35	27.0	2.3	23.7	32.6	37	n.s.
br–l to the parietal bone	mm	28.1	3.0	21.3	33.1	35	27.3	2.7	21.7	33.7	37	n.s.
ba–l to the occipital bone	mm	38.5	3.3	31.1	48.0	35	37.3	3.4	30.1	44.8	37	n.s.
Thickness of the frontal bone	mm	4.2	0.8	2.7	6.3	35	4.2	0.8	2.8	5.7	37	n.s.
Thickness of the parietal bone	mm	4.9	1.0	2.9	7.7	35	5.1	0.7	3.9	6.4	37	n.s.
Thickness of the occipital bone	mm	4.3	1.5	1.8	7.8	35	3.7	1.4	2.1	7.6	37	n.s.

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$.

The anterior cranial base (s–n) and posterior cranial base (s–ba) increased in length during the observation period in both sexes. In females the increase in length of s–n and s–ba ceased at 15 years of age. In males these continued to increase to at least 18 years of age. The mean difference between males and females was statistically significant in the three oldest age groups (Figure 2a,b).

The cranial base angle (n–s–ba) was stable in females, but decreased in males during the observation period. No statistical differences were found between the male and female age groups (Figure 2c).

The diameter (n–l) and length (n–opc) of the neurocranium increased in both sexes during the observation period. In the male group they increased to 18 years, and in the female group to 15 years. The differences

Table 4 Cephalometric standards for males and females at 9 years of age.

		Male (N = 35)					Female (N = 37)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	91.1	2.6	85.5	95.3	32	92.1	3.2	86.9	98.8	36	n.s.
n–s–ba	deg	130.1	4.5	118.6	138.9	35	130.9	4.9	121.1	140.3	37	n.s.
s–n	mm	64.5	2.6	60.6	72.5	35	63.5	1.8	60.2	68.0	37	n.s.
s–ba	mm	39.9	2.5	35.0	44.3	35	38.9	2.6	34.3	43.8	37	n.s.
s–f	mm	88.6	3.8	81.5	98.7	32	87.9	3.4	82.9	97.4	36	n.s.
n–br	mm	107.6	4.1	100.1	115.5	32	105.6	5.2	96.8	117.5	36	n.s.
s–br	mm	99.3	3.8	94.2	109.3	32	97.1	3.6	93.0	107.0	36	*
ba–br	mm	134.4	4.2	126.6	144.2	32	131.9	3.6	125.5	143.4	36	*
br–l	mm	124.0	5.3	112.5	132.7	32	120.3	5.2	110.2	135.0	35	**
s–l	mm	115.2	5.6	103.8	124.1	34	112.7	6.3	101.2	129.1	35	n.s.
n–l	mm	172.5	7.0	146.7	183.3	35	169.5	6.7	156.4	184.0	35	n.s.
n–opc	mm	175.1	5.3	165.1	186.9	35	171.6	7.5	156.5	186.9	37	*
ba–l	mm	114.7	5.4	101.1	125.2	35	112.3	5.6	101.4	126.8	35	n.s.
n–br to the frontal bone	mm	26.4	2.2	21.0	32.9	32	26.8	2.5	23.3	33.5	36	n.s.
br–l to the parietal bone	mm	28.2	2.9	20.9	33.2	31	27.4	2.5	21.6	32.3	35	n.s.
ba–l to the occipital bone	mm	38.8	3.3	31.9	45.8	34	37.6	3.7	32.5	46.3	35	n.s.
Thickness of the frontal bone	mm	4.5	0.7	3.1	6.3	32	4.6	0.9	3.1	6.3	36	n.s.
Thickness of the parietal bone	mm	5.5	0.9	3.9	8.2	31	5.6	0.7	4.3	7.5	35	n.s.
Thickness of the occipital bone	mm	4.6	1.5	2.8	8.4	35	4.1	1.1	2.3	8.0	35	n.s.

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$.

Table 5 Cephalometric standards for males and females at 12 years of age.

		Male (N = 35)					Female (N = 37)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	89.2	3.0	82.2	95.6	27	89.6	3.1	85.2	95.8	29	n.s.
n–s–ba	deg	129.5	4.3	120.3	137.7	35	130.2	4.9	121.4	141.9	37	n.s.
s–n	mm	66.1	3.0	60.6	74.5	35	65.5	2.2	61.4	70.8	37	n.s.
s–ba	mm	41.7	3.0	35.6	47.4	35	41.0	2.6	65.1	46.0	37	n.s.
s–f	mm	88.7	4.0	81.3	98.5	27	87.6	2.9	82.6	96.7	29	n.s.
n–br	mm	108.8	4.1	102.7	116.7	27	107.2	5.9	98.5	127.9	29	n.s.
s–br	mm	99.0	3.5	94.4	106.8	27	96.5	3.2	90.6	104.5	29	**
ba–br	mm	135.4	4.0	126.5	143.3	27	133.0	4.8	114.0	139.9	29	n.s.
br–l	mm	124.5	5.7	113.9	138.9	27	120.9	5.3	109.5	133.8	29	*
s–l	mm	115.9	5.4	104.9	125.9	35	113.9	6.2	102.0	130.5	37	n.s.
n–l	mm	176.2	5.3	165.1	185.7	35	173.0	6.7	159.2	186.6	37	*
n–opc	mm	178.3	5.3	167.5	190.6	35	175.7	7.1	160.1	189.7	37	n.s.
ba–l	mm	115.3	4.6	100.6	122.4	35	113.5	5.8	102.2	127.8	37	n.s.
n–br to the frontal bone	mm	26.0	2.4	20.9	32.2	27	26.4	2.7	23.1	32.8	29	n.s.
br–l to the parietal bone	mm	28.0	2.8	20.0	32.1	27	27.5	3.0	20.8	32.3	28	n.s.
ba–l to the occipital bone	mm	39.3	3.1	34.3	45.5	35	37.8	3.9	31.6	47.7	37	n.s.
Thickness of the frontal bone	mm	4.7	0.8	3.4	6.8	27	5.2	1.0	3.2	7.7	29	*
Thickness of the parietal bone	mm	6.0	1.2	3.6	8.9	23	6.4	0.9	4.9	8.6	28	n.s.
Thickness of the occipital bone	mm	5.0	1.7	2.5	9.8	35	4.6	1.2	2.6	9.1	37	n.s.

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$.

between the male and female groups were statistically significant in all age groups with an exception for the 9 (n–l) and 12 year (n–opc) groups. The level of significance was highest in the three oldest age groups (Figure 3a,b).

The height of the neurocranium decreased somewhat during the observation period as shown by the variables s–br and ba–br. The increase in ba–br in the early age groups was a result of the increase in length of the posterior cranial base (Figure 3c,d).

In the anterior part of the neurocranium the changes were only minor during the observation period for both sexes. The prominence (s–n–f) and curvature of the frontal bone decreased as a result of the increase in length of the anterior cranial base. The frontal bone was more prominent in females in all age groups, with a

Table 6 Cephalometric standards for males and females at 15 years of age.

		Male (*N* = 35)					Female (*N* = 37)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	84.9	5.6	68.8	90.0	15	88.0	2.8	82.9	92.9	22	*
n–s–ba	deg	128.9	4.6	120.0	137.6	35	130.1	4.7	122.0	140.1	37	n.s.
s–n	mm	68.8	2.8	64.7	77.3	35	67.1	2.1	62.8	72.2	37	**
s–ba	mm	43.7	2.8	38.1	49.0	35	41.8	2.9	37.1	47.4	37	**
s–f	mm	88.1	3.5	81.9	92.4	15	87.9	2.1	84.2	93.5	22	n.s.
n–br	mm	109.5	3.9	104.7	117.6	14	107.3	3.5	100.8	113.9	22	n.s.
s–br	mm	96.7	3.2	89.8	101.9	14	95.9	3.8	83.8	102.0	22	n.s.
ba–br	mm	135.1	4.5	112.6	147.3	14	133.8	3.4	127.4	139.2	22	n.s.
br–l	mm	123.1	8.0	109.4	139.0	14	120.1	4.3	111.5	129.1	22	n.s.
s–l	mm	117.8	5.9	106.0	127.9	35	113.9	5.8	100.4	125.0	37	**
n–l	mm	180.4	5.7	168.2	192.6	35	174.8	5.9	160.9	187.0	37	***
n–opc	mm	182.5	5.7	169.1	194.2	35	177.5	7.2	160.4	190.8	37	**
ba–l	mm	117.9	5.6	104.4	130.1	35	115.1	6.3	104.7	139.1	37	n.s.
n–br to the frontal bone	mm	24.8	1.5	21.2	27.3	13	25.8	1.5	23.1	28.3	22	n.s.
br–l to the parietal bone	mm	27.2	1.7	24.2	29.5	12	27.2	2.1	24.3	30.9	19	n.s.
ba–l to the occipital bone	mm	39.8	4.1	32.0	50.2	35	38.0	3.7	31.7	46.5	37	*
Thickness of the frontal bone	mm	5.1	0.9	3.9	6.8	15	5.6	1.2	3.6	8.7	22	n.s.
Thickness of the parietal bone	mm	7.1	1.1	5.5	9.5	19	6.9	1.4	4.0	9.5	19	n.s.
Thickness of the occipital bone	mm	5.8	2.0	2.4	10.1	35	5.1	1.6	2.8	10.5	37	n.s.

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

Table 7 Cephalometric standards for males and females at 18 years of age.

		Male (*N* = 35)					Female (*N* = 37)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	85.5	3.5	80.3	91.2	6	88.3	3.8	83.3	99.1	17	n.s.
n–s–ba	deg	128.3	4.7	119.2	137.7	35	130.1	4.8	122.3	140.4	37	n.s.
s–n	mm	70.3	3.0	64.9	79.2	35	67.4	2.1	63.0	72.8	37	***
s–ba	mm	44.4	2.5	39.6	49.6	35	41.6	2.6	35.5	45.8	37	***
s–f	mm	87.8	3.5	83.3	92.7	5	87.7	2.5	84.4	93.6	17	n.s.
n–br	mm	110.6	2.7	106.7	113.5	5	107.5	3.9	100.8	114.0	17	n.s.
s–br	mm	97.7	3.0	93.5	100.6	5	96.0	3.4	91.6	102.3	17	n.s.
ba–br	mm	135.0	4.9	130.0	410.2	5	133.2	4.5	123.6	139.2	17	n.s.
br–l	mm	124.6	10.3	114.3	138.5	5	121.2	7.0	108.1	136.2	17	n.s.
s–l	mm	118.4	5.9	107.3	128.1	35	114.9	5.9	102.8	131.3	37	*
n–l	mm	182.7	5.7	171.0	193.7	35	175.8	6.3	161.8	188.9	37	***
n–opc	mm	184.7	5.7	174.5	197.0	35	178.4	7.0	162.4	192.1	37	***
ba–l	mm	118.7	5.7	104.1	129.6	35	115.2	6.1	104.9	134.4	37	*
n–br to the frontal bone	mm	24.4	1.9	21.1	25.5	5	25.6	1.9	23.0	29.2	17	n.s.
br–l to the parietal bone	mm	25.5	0.6	24.9	26.3	4	27.1	2.6	23.7	31.6	15	n.s.
ba–l to the occipital bone	mm	40.4	3.9	34.2	51.1	35	37.8	3.8	31.2	46.6	37	**
Thickness of the frontal bone	mm	5.1	0.9	4.3	6.3	5	6.0	1.3	4.1	8.9	17	n.s.
Thickness of the parietal bone	mm	7.9	1.1	7.0	9.1	3	7.5	1.4	5.3	10.0	15	n.s.
Thickness of the occipital bone	mm	6.4	2.0	2.9	11.2	35	5.3	1.6	2.8	8.8	37	*

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

statistically significant result at 15 years ($P < 0.05$). A significant result was not established in the older age groups due to the limited number of valid measurements in males. Females showed a greater curvature of the frontal bone (Figure 4a–e).

In the middle part of the neurocranium the distance br–l was stable for males and females throughout the observation period. The distance in males exceeded that of the females and was statistically significant in the three youngest age groups. The curvature of the parietal bone was stable, and the reduction for the male groups at 15 and 18 years was probably a result of a smaller number of valid measurements in these age groups (Figure 5a–c).

Table 8 Cephalometric standards for males and females at 21 years of age.

		Male (N = 19)					Female (N = 15)					Significance
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number	
s–n–f	deg	87.9	–	85.7	90.3	3	85.1	–	82.9	87.3	2	–
n–s–ba	deg	127.6	5.0	118.6	136.1	19	130.5	3.6	123.0	136.8	15	n.s.
s–n	mm	70.5	3.4	66.4	80.0	19	67.5	1.7	64.6	71.7	15	**
s–ba	mm	45.0	1.8	42.0	48.9	19	41.7	2.4	38.8	45.9	15	***
s–f	mm	92.5	–	92.3	92.7	2	87.4	–	86.4	88.3	2	–
n–br	mm	113.8	–	113.6	114.0	2	111.4	–	110.1	113.0	2	–
s–br	mm	99.8	–	98.7	100.9	2	97.1	–	94.5	99.6	2	–
ba–br	mm	140.3	–	139.3	141.3	2	133.2	–	130.5	135.8	2	–
br–l	mm	121.8	–	119.9	123.6	2	115.6	–	113.5	117.6	2	–
s–l	mm	117.5	6.0	105.9	127.3	19	114.4	5.3	101.9	123.0	15	n.s.
n–l	mm	182.4	6.1	169.4	191.3	19	175.5	5.9	161.8	185.0	15	**
n–opc	mm	184.8	6.1	174.1	196.4	19	177.9	6.4	162.6	187.9	15	**
ba–l	mm	118.4	6.6	103.8	130.1	19	113.8	4.7	103.0	120.4	15	*
n–br to the frontal bone	mm	28.7	–	26.6	30.7	2	26.6	–	25.4	27.7	2	–
br–l to the parietal bone	mm	27.6	–	26.9	28.3	2	24.2	–	22.6	25.8	2	–
ba–l to the occipital bone	mm	39.1	3.2	33.1	45.0	19	36.5	3.8	31.2	42.9	15	*
Thickness of the frontal bone	mm	6.1	–	5.6	6.6	2	6.4	–	6.2	6.6	2	–
Thickness of the parietal bone	mm	7.0	–	6.2	7.8	2	8.5	–	7.6	9.4	2	–
Thickness of the occipital bone	mm	6.3	2.4	2.8	12.4	19	4.8	1.2	3.1	6.8	15	*

n.s., not significant; * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

Table 9 Curvature indices for the frontal, parietal, and occipital bones for males and females in all age groups.

	Curvature Index	Male (N = 35)					Female (N = 37)				
		Mean	SD	Min	Max	Number	Mean	SD	Min	Max	Number
6 year group	frontal bone	25.2	1.8	21.8	29.8	35	26.0	1.4	23.3	29.5	37
	parietal bone	22.7	1.9	17.6	25.8	35	22.8	1.9	19.8	27.6	37
	occipital bone	34.0	2.7	28.5	38.6	35	33.7	2.8	27.6	39.2	37
9 year group	frontal bone	24.5	1.7	20.8	29.4	32	25.4	1.5	22.8	29.2	36
	parietal bone	22.7	1.8	17.2	26.0	31	22.8	2.0	18.8	26.9	35
	occipital bone	33.8	2.7	28.3	39.2	34	33.5	2.9	27.8	40.1	35
12 year group	frontal bone	23.9	1.8	20.2	28.2	27	24.6	1.6	22.0	28.8	29
	parietal bone	22.5	1.9	16.4	25.5	27	22.7	2.1	19.0	27.5	28
	occipital bone	34.1	2.5	28.8	40.1	35	33.3	2.9	27.4	39.3	37
15 year group	frontal bone	22.6	1.5	20.1	24.8	12	24.0	1.0	21.8	25.7	22
	parietal bone	22.2	1.3	19.6	23.7	11	22.6	1.6	19.9	26.8	19
	occipital bone	33.8	3.1	28.2	40.9	35	33.0	2.9	26.5	38.8	37
18 year group	frontal bone	22.0	1.3	19.8	23.2	5	23.8	1.2	21.7	26.1	17
	parietal bone	20.9	1.9	18.1	22.2	4	22.3	2.3	19.0	26.6	15
	occipital bone	34.0	2.7	28.7	40.7	35	32.9	3.0	27.0	39.2	37
21 year group*	frontal bone	25.2	2.5	23.4	26.9	2	23.8	1.0	23.1	24.5	2
	parietal bone	22.7	0.3	22.4	22.9	2	20.9	1.4	19.9	21.9	2
	occipital bone	33.1	3.0	28.9	40.8	19	32.1	2.9	27.5	37.1	15

* Male, N = 19; female, N = 15.

In the posterior part of the neurocranium the distances s–l and ba–l increased during the observation period to 15 years in the female group and to 18 years in the male group, with the mean values for the male group exceeding those of the female group. The mean values for males and females differed significantly at 15 and 18 years of age for s–l and at 18 and 21 years of age for ba–l (Figure 6a,b).

The maximum distance from the cord ba–l to the outer surface of the occipital bone increased during the observation period in both sexes to 15 years in females and 18 years in males. The differences in the mean values between the male and female groups were statistically significant only for the three oldest groups, with the highest significance at 18 years of age (Figure 6c).

The curvature of the occipital bone decreased slowly in females throughout the observation period, whilst the mean values for males seemed to be constant (Figure 6d).

The thickness of the calvaria was measured at three locations: on the frontal, parietal, and occipital bones. The differences between the bones were obvious: the frontal and occipital bones being thinner than the parietal bone. The thickness of the frontal bone was statistically greater in females with a significance of $P < 0.05$ at 12 years. The difference was larger in the older age groups, but a statistically significant result could not be reached due to the limited number of valid measurements in the male groups (Figure 7a–c).

Discussion

The lateral cephalograms analysed in this study were selected from the files of Oslo University Growth Archive and they represent several age cohorts of Caucasian individuals from a limited geographical area in Norway. This archive is considered to be homogeneous and representative of the population living in this area (Aasheim and Øgaard, 1993; El-Batouti *et al.*, 1994).

The criteria chosen for selection of the sample in the present study has the disadvantage of limiting the number of individuals included but the advantage of providing a longitudinal set of data. Tanner (1962) pointed out the advantages of purely longitudinal data over mixed or cross-sectional data.

Although radiographic cephalometric reference standards for the dentofacial area and cranial base are available for various ages, ethnic groups, and gender, longitudinal reference standards for the neurocranium during growth have not been published previously.

As various levels of accuracy have to be accepted for different landmarks (Björk, 1947; Stabrun and Danielsen, 1982), it is difficult to establish a general definition of what should be considered as unacceptable or gross error. The largest source of error in cephalometrics is the localization of reference points. In the present study as there were no systematic differences in the location of the reference points in the repeated analysis of cephalograms, the analyses of the total sample can be regarded as valid.

The results from the present study indicate that marked age-related changes occur in several variables, supporting the need for age-specific cephalometric reference data on the neurocranium. The most pronounced changes during the observation period were

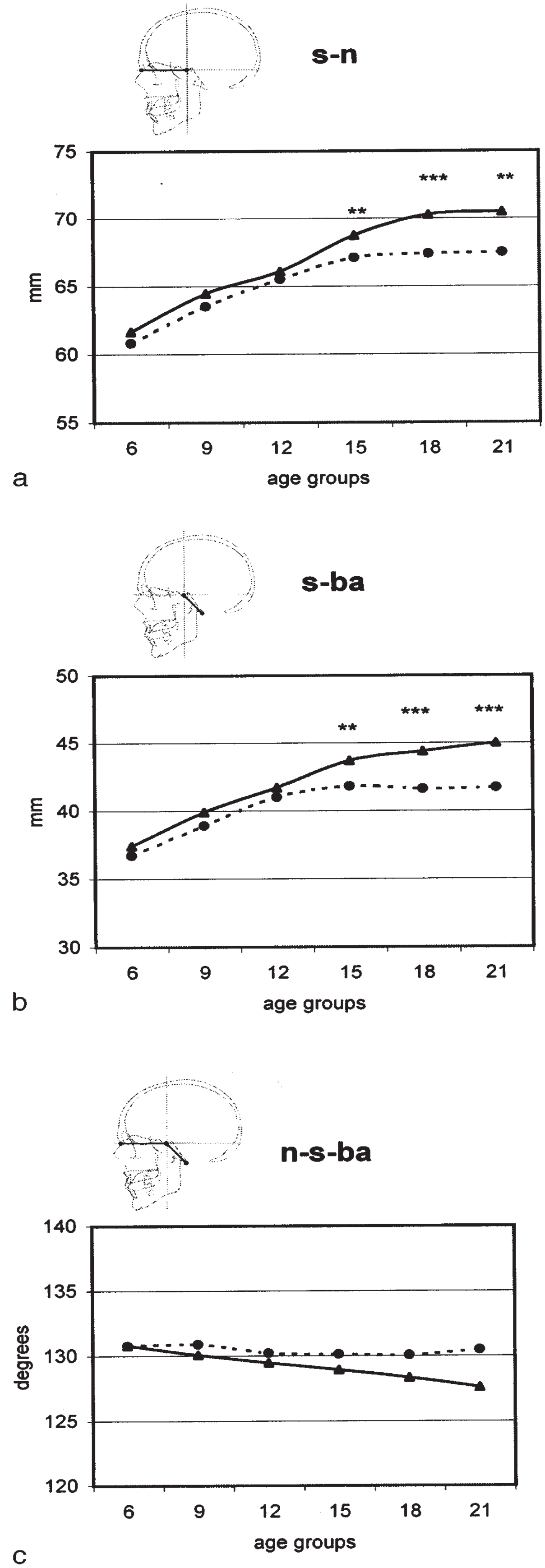


Figure 2 Growth curves from the Oslo University Growth Archive showing variables from the cranial base from 6 to 21 years of age. ▲, males; ●, females. (a) Length of the anterior cranial base (n–s). (b) Length of the posterior cranial base (s–ba). (c) External cranial base angle (n–s–ba). Levels of significance between males and females: ** significant at $P < 0.01$; *** significant at $P < 0.001$.

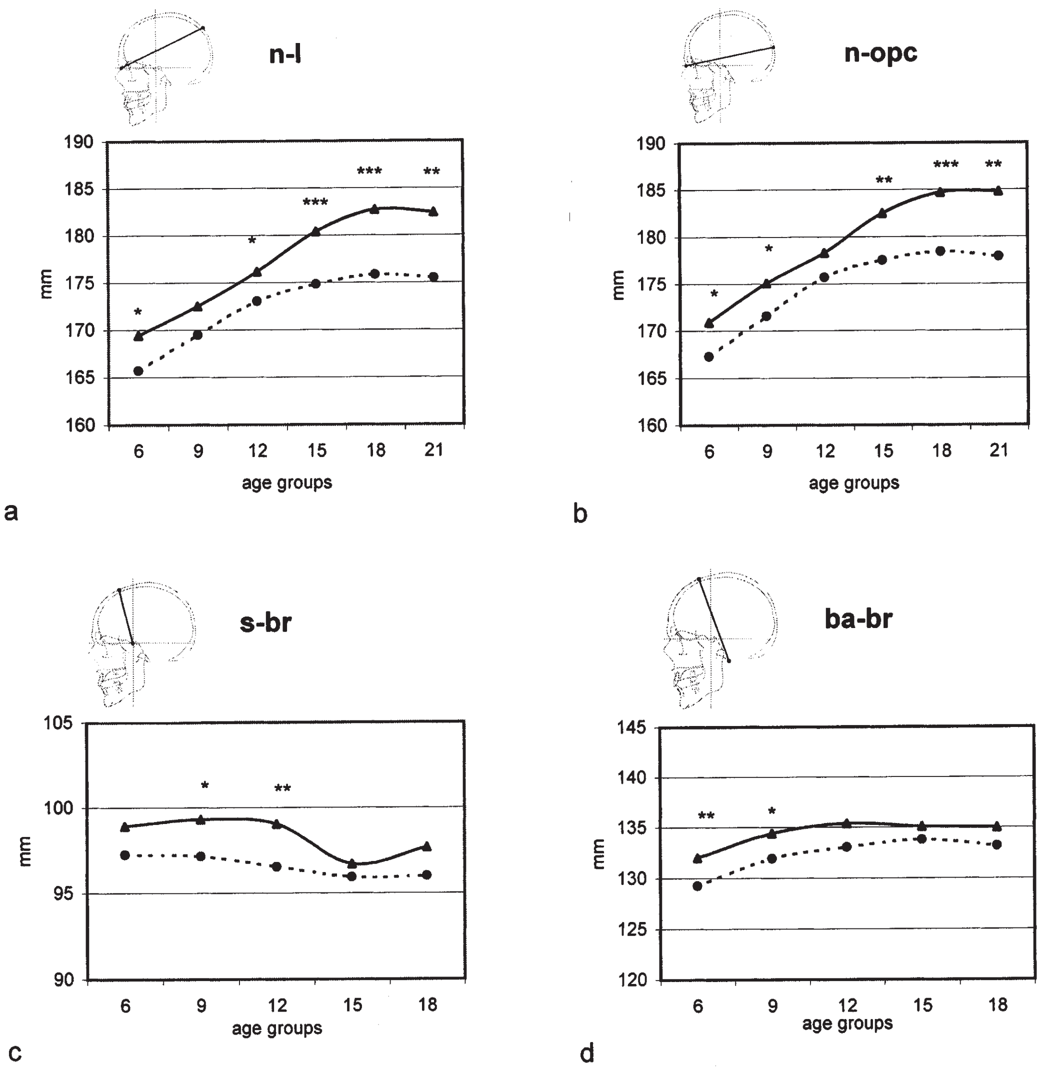


Figure 3 Growth curves from the Oslo University Growth Archive showing the length and height of the neurocranium from 6 to 21 years of age. ▲, males; ●, females. (a) Diameter n–l. (b) Length n–opc. (c) Height s–br. (d) Height ba–br. Levels of significance between males and females: * significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

shown in the diameter and length of the neurocranium, in the length of the anterior and posterior cranial base, and in the curvature of the frontal and occipital bones. No or only minor changes were shown in the vertical dimension of the anterior and middle part of the neurocranium.

The most pronounced differences between the sexes were observed after the age of 12 years. Males consistently demonstrated significantly larger values for most of the variables measured, particularly in the older age groups. Females, on the other hand, had larger changes than males, particularly between 9 and 12 years of age. This could be attributed to the earlier pubertal growth spurt in females. This supports the findings of previous investigations (Mitani, 1977; Prahl-Andersen *et al.*, 1979).

Both cranial base lengths analysed in this study increased during the observation period in both sexes and were larger in males than in females. This is in accordance with several authors (Stamrud, 1959; Riolo *et al.*, 1974; Roche and Lewis, 1974; Broadbent *et al.*, 1975; Mitiani, 1977; Baughan *et al.*, 1979; Lewis *et al.*, 1985; Bhatia and Leighton, 1993; Henneberke and Prahl- Andersen, 1994). Whilst the size differences between the sexes were established at 6 years of age, they were statistically significant only at the age of 15 years.

Females did not show a pubertal growth spurt in either of the cranial base distances, whereas the male group showed signs of pubertal growth spurts in both. The pubertal growth spurt in the anterior cranial base

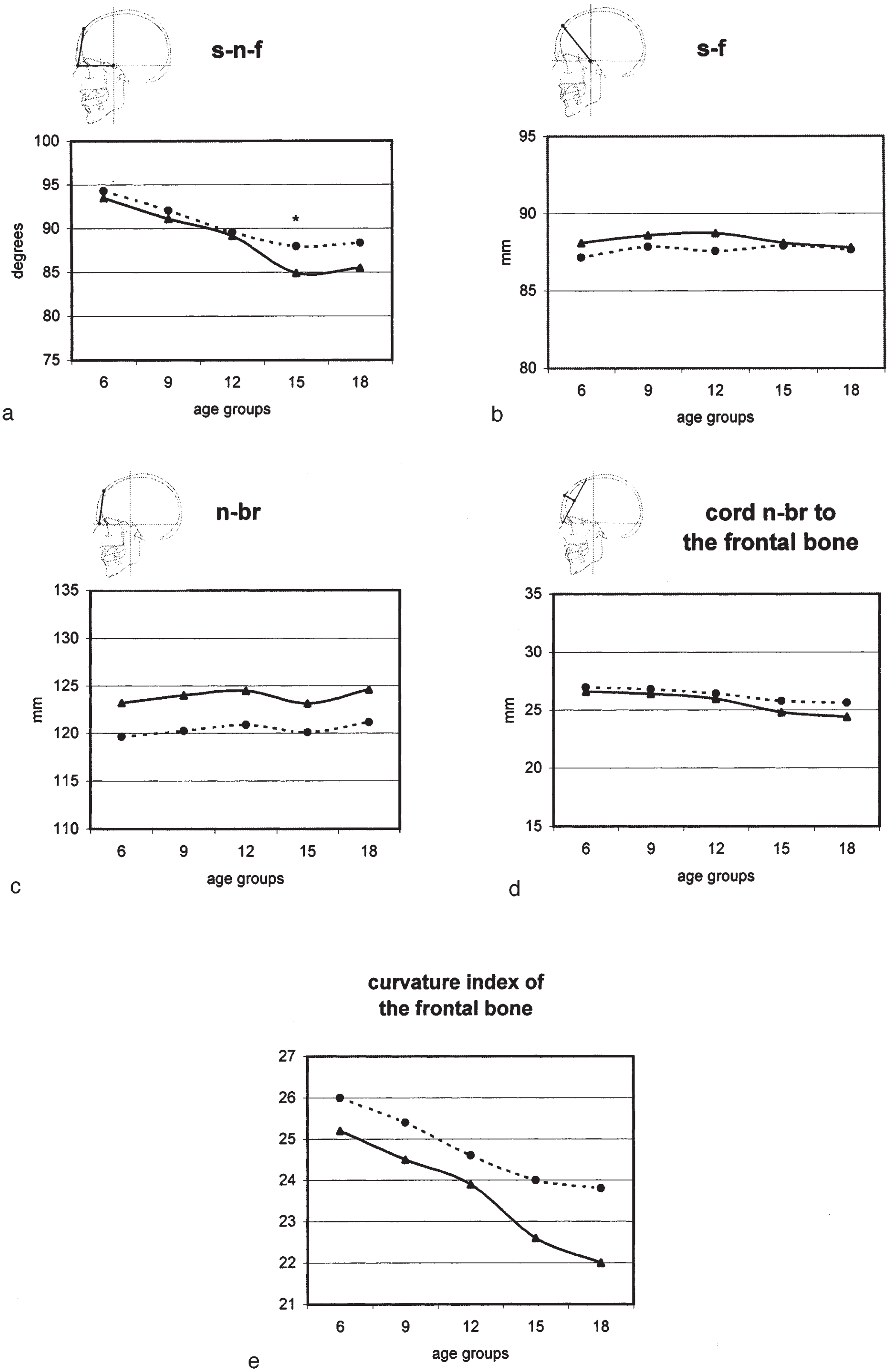


Figure 4 Growth curves from the Oslo University Growth Archive showing variables from the anterior part of the neurocranium from 6 to 18 years of age. ▲, males; ●, females. (a) Prominence of the frontal bone (s–n–f). (b) Distance s–f. (c) Distance n–br. (d) Cord n–br to the frontal bone. (e) Curvature index of the frontal bone. Level of significance between males and females: * significant at $P < 0.05$.

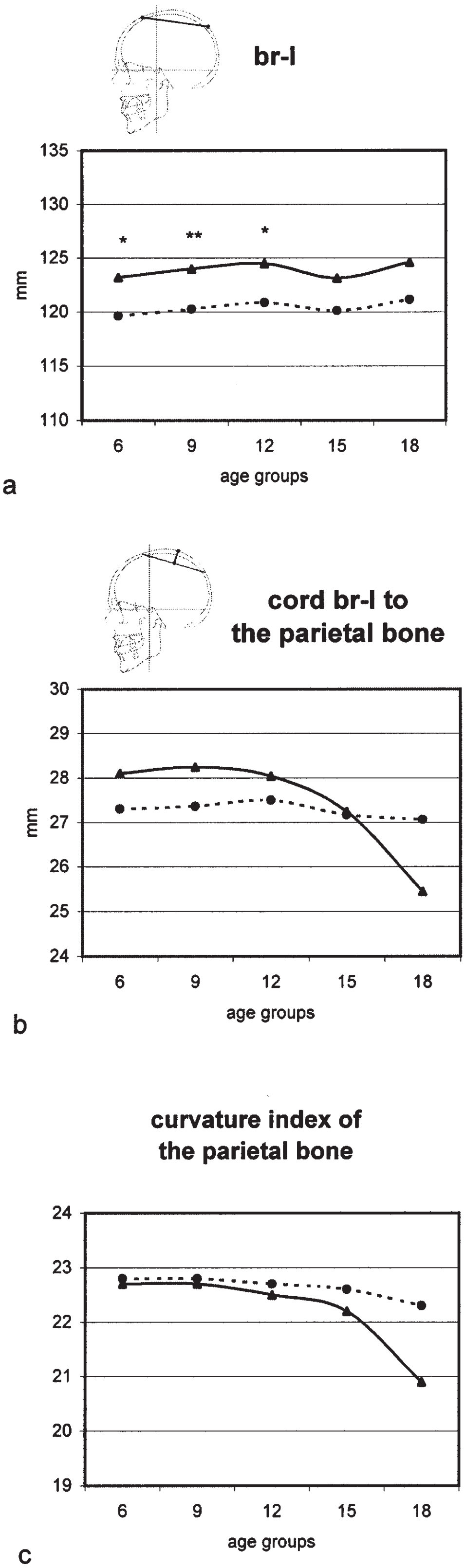


Figure 5 Growth curves from the Oslo University Growth Archive showing variables from the middle part of the neurocranium from 6 to 18 years of age. ▲, males; ●, females. (a) Distance br–l. (b) Cord br–l to the parietal bone. (c) Curvature index of the parietal bone. Levels of significance between males and females: * significant at $P < 0.05$; ** significant at $P < 0.01$.

was more evident than in the posterior cranial base. In agreement with Henneberke and Prahl-Andersen (1994) no pubertal growth spurt was found for the female group, whereas Roche and Lewis (1974), Mitiani (1977), Baughan *et al.* (1979), and Lewis *et al.* (1985) found pubertal growth spurts for both males and females in the cranial base. Most growth curves in females show changes over a relatively long period during puberty, whereas males show a sharp peak in growth rate followed by a rapid decline (Prahl-Andersen *et al.*, 1979).

The growth of the various parts of the cranial base is differentiated, with the anterior part completed earlier than the posterior (Friede, 1981). In the present study this could be shown for the male group, where the growth curve for the anterior cranial base flattened out after 18 years but the posterior part continued to increase up to 21 years. No such difference could be detected in the female group where both growth curves flattened out after 15 years of age.

The cranial base angle showed only minor changes during the observation period for the female group and decreased in the male group. This pattern is in accordance with previous mixed longitudinal studies such as Thilander *et al.* (1982).

The present results from the cranial base measurements were also compared with the two most widely used normative standards: the Michigan (Riolo *et al.*, 1974) and Bolton Growth Studies (Broadbent *et al.*, 1975). Comparison with the Michigan Growth Study was difficult as no information on the enlargement factor of the radiographs was given. The results from the Bolton Growth Study correspond well with those from this investigation.

The length of the neurocranium from nasion to lambda (n–l) increased for both sexes during the observation period with a marked pubertal growth peak in the male group between 12 and 15 years. A similar pubertal peak was not found in the female group. The mean value for males at 21 years is in accordance with the results of Solow and Tallgren (1976) in their analysis of the craniofacial morphology of Danish male students. The results for both sexes were similar to those of Huggare *et al.* (1986), although that data was mixed cross-sectional with great differences within and between the age groups.

The increase in length of the neurocranium from nasion to opisthocranion (n–opc) in both sexes throughout the observation period could in part be explained by the forward displacement of nasion. The mean distance at 21 years was somewhat shorter than reported by Jensen (1994) for adult male and female dental students, but more in agreement with the results given by Björk (1955) in his Swedish male adult group.

The prominence of the frontal bone (s–n–f) is closely related to the changes in anterior cranial base length.

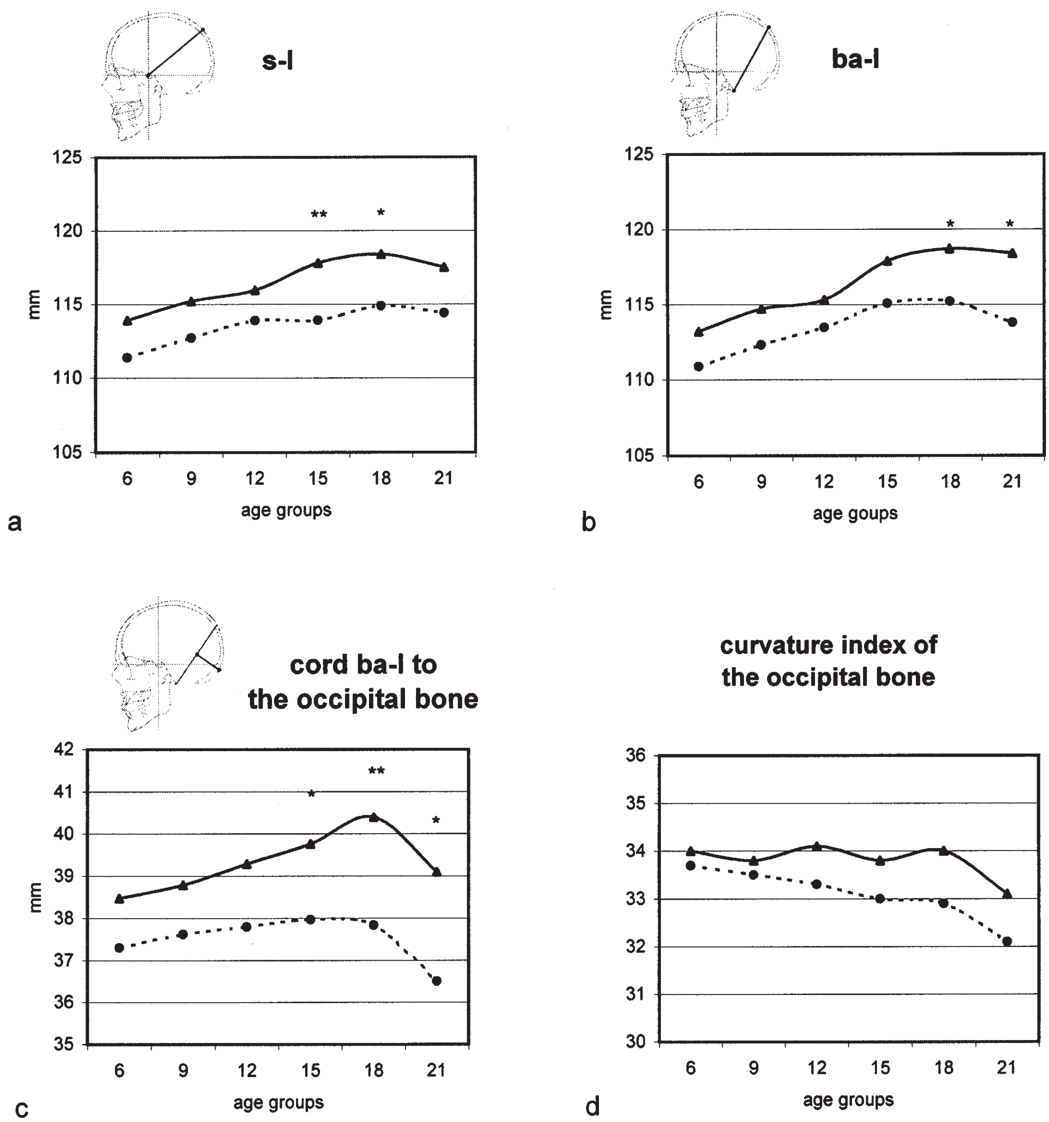
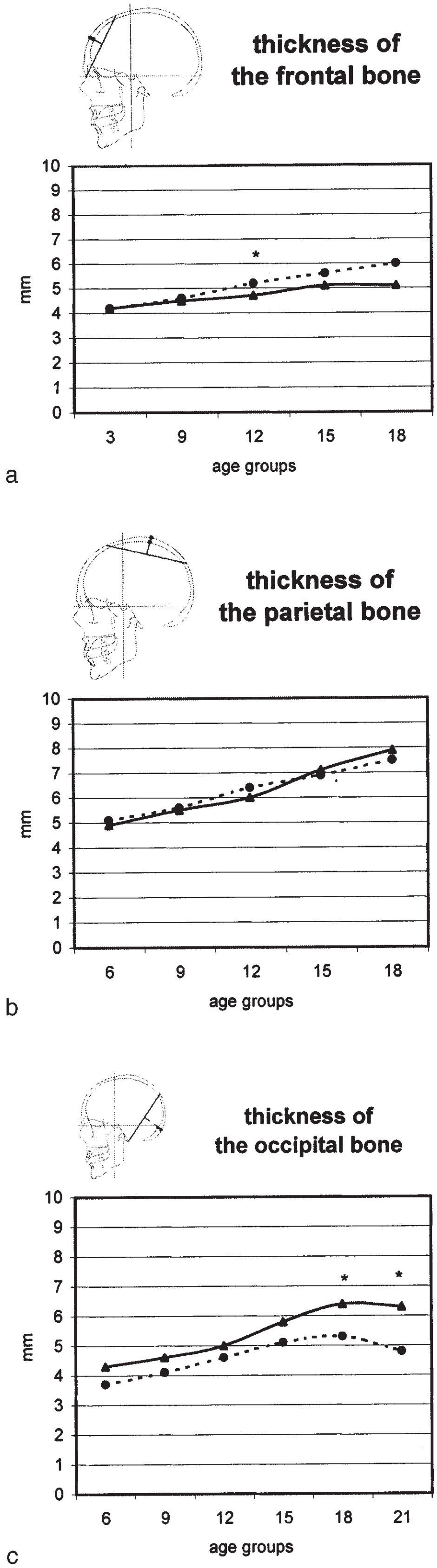


Figure 6 Growth curves from the Oslo University Growth Archive showing variables from the posterior part of the neurocranium from 6 to 21 years of age. ▲, males; ●, females. (a) Distance s–l. (b) Distance ba–l. (c) Cord ba–l to the occipital bone. (d) Curvature index of the occipital bone. Levels of significance between males and females: * significant at $P < 0.05$; ** significant at $P < 0.01$.

As the anterior cranial base increases, the angle s–n–f decreases at the same rate, which means that there is no spatial change in the position of the reference point, frontale. This conclusion was confirmed by the measurement of the distance from sella to frontale (s–f), as it was almost constant for both sexes throughout the observation period. The female group consistently showed a more prominent frontal bone. A statistically significant difference between the sexes was found at 15 years and this could be a result of the pubertal growth spurt seen in the anterior cranial base length in males. The greater prominence of the frontal bone in the female group may be related to a more strongly curved frontal bone. This is in agreement with results from the analysis of the Danish adult male and female dental students (Ingerslev and Solow, 1975), but their values were lower than the observed mean values in this study, indicating that these values might further decrease during the third decade of life. Björk (1955) also found the angle s–n–f to diminish in his investigation of Swedish boys from 12 to 20 years.

The anterior height of the neurocranium (s–br) was almost constant throughout the observation period for both sexes. Huggare *et al.* (1986), in a mixed cross-sectional material, found that this distance increased from childhood to adolescence in females, but there were only minor changes in males.



The stability of the cranial base angle in the females during the observation period indicates that changes in the variables including the reference point basion were related to the lengthening of the posterior cranial base. On the other hand, the decrease in the cranial base angle in males might have some influence, particularly on the cord basion to lambda.

During the growth period bony apposition on the endo- and ectocranial surfaces of the calvaria results in an increase in calvarial bone thickness. This process of remodelling also influences the changes in curvature of the calvarial bones during their outward displacement (Enlow, 1982). The curvature index for the frontal, parietal, and occipital bones, respectively, was used for descriptive purposes. The use of indices is, however, doubtful from a statistical viewpoint. The curvature of the calvarial bones in the present study confirms the results of the adult male sample presented by Kisling (1966).

Conclusions

The findings of this study show that the neurocranium is larger in size in males than in females. This longitudinal normative cephalometric data for a number of variables in the neurocranium specific for age and gender throughout the growth period provides normal reference standards for the description of the neurocranium in craniofacial syndromes.

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Figure 7 Growth curves from the Oslo University Growth Archive showing the thickness of the calvaria from 6 to 21 years of age. ▲, males; ●, females. Thickness of (a) frontal, (b) parietal, and (c) occipital bones. Levels of significance between males and females: * significant at $P < 0.05$.

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