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ZBYNĚK ŠMAHEL, DANIEL ŠABÍK, MICHAELA TOMANOVÁ, ŽIVA MÜLLEROVÁ

# BASIC CHARACTERISTICS OF THE POSTNATAL DEVELOPMENT OF THE HUMAN CRANIUM

*ABSTRACT: The authors have analyzed by roentgencephalometry the films of 27 healthy boys and 29 girls aged 5 years, and those of 37 healthy adult men and 35 women. The linear dimensions were adjusted to X-ray magnification to obtain their actual values and all data thus present the Czech norms. To evaluate the amount of growth the differences between the dimensions in childhood and adult age were expressed in percent of the initial value of the characteristic in childhood.*

*During the investigated period the least growth was recorded in the neurocranium (neural growth type), particularly in height. The growth rate of the length and width of the skull base was transitional between the neural and facial growth type; the postsellar length of the base showed a similar growth rate as facial dimensions. The growth of the face in vertical direction exceeded its growth in anteroposterior and transverse directions. The depth of the maxilla and of the bony framework of the nasopharynx showed the slightest growth rate while the mandible, in particular its ramus showed the highest growth rate. The latter approached the general skeletal type of growth. Of the widths dimensions the width of the nasal cavity and the bigonial distance showed the highest and the width of the orbit the lowest (neural growth type) growth rate. On the soft profile the most intense growth rate was recorded in the depth of the nose (the nose prominence increases) and the lowest growth rate in the height of the upper lip.*

*The angular characteristics indicate a diminution of the slope of the forehead, posteriorotation of the neurocranium and more posterior inclination of the foramen magnum in adult age; the curvature of the cranial base diminished only very slightly between childhood and adult age. The protrusion of the upper jaw changed very little with increasing age, while in the lower jaw it increased definitely and thus the sagittal jaw relations and the convexity of the face were reduced. The steepness of the mandibular body diminished (anterior growth rotation of the mandible) similarly as the slope of the occlusal plane, the angle of vertical jaw relations, the gonial angle and the angle of the chin. The mandibular ramus is in a steeper position in adult age while the direction of mandibular growth does not change with age. Also the slope of the palatal plane and position of the maxilla in relation to the base did not change (the palate grows in distal and anterior direction). The permanent upper and lower incisors are, as compared with deciduous ones, markedly proclined and the interincisal angle is reduced. A greater proclination is found in adult age also in the alveolar processes and nasal bones. On the soft profile the protrusion of the upper and lower face becomes more marked in adults. Therefore, the convexity of the face does not change but the convexity of the profile including the nose increases. All differences in shape are the result of a differing growth rate of individual structures.*

*Intersexual differences in the size of the cranium in adult age amount to 5–10% in the majority of facial characteristics, 3–5% in the neurocranium. In childhood the differences are smaller, 1–6%. This results from the longer-lasting growth of the cranium in boys than in girls with a larger final size in males. On the contrary the shape of the cranium and of its components showed virtually no significant intersexual differences. In adult age, females have a more vaulted forehead, a more anterior inclination of foramen magnum and greater proclination of the upper alveolar process with a greater maxillary overjet, in childhood they have more protruding jaws.*

*KEY WORDS: X-ray cephalometry – Normal population – Craniofacial growth and development – 5 years and adult age – Amount of growth – Changes of shape – Intersexual differences – Growth patterns – Czech norms*

## INTRODUCTION

There is relatively little information on the character and variability of the development of the human cranium and its different components during the postnatal period, as cephalometric studies record mostly only developmental changes in size and not shape and longitudinal roentgencephalometric studies are practically impossible in healthy subjects. Longitudinal roentgencephalometric data are reported in the literature only exceptionally and are focused as a rule on the specific needs of orthodontic treatment (Bishara *et al.* 1984, El-Batouti *et al.* 1994).

Findings assembled hitherto are therefore based mostly on cross-sectional studies or derived from investigations of patients, usually those undergoing orthodontic treatment. However, in such studies the developmental patterns are altered to a different extent. There are also very few cross-sectional roentgencephalometric data from the normal population. In the literature no data comprising the central European and Slavonic populations were found. Relevant data are however essential for investigations of abnormal development in congenital defects and growth disorders, post-traumatic conditions, etc. Standards of varied origin and age are used. Growth standards were elaborated in particular for the populations of North America (Broadbent *et al.* 1975, Riolo *et al.* 1974, Bishara *et al.* 1984, 1985), Anglo-Saxon countries (Kerr 1979, Trenouth *et al.* 1985, Schmuth *et al.* 1988) or Scandinavian countries (Björk 1947, El-Batouti *et al.* 1994). Very frequently they concern only a certain range of age and usually only the basic parameters of the lateral facial projection. Standards of the anteroposterior projection are rare (Saksena 1990), similar to characteristics of the neurocranium.

The submitted study is based on the analysis of X-ray cephalometric films of healthy 5-year-old children and adults of both sexes assembled in the past as controls for investigations of the craniofacial development in patients with facial clefts. The objective was to provide standards characterizing the size, shape and positional parameters of the cranium for the Czech population which is typical for the brachycephalic, euryprosope Slavonic population, and by comparing findings in children and adults describe the developmental characteristics of the cranium in the postnatal period. Although different subjects were involved during childhood and adult age the interval is long enough to evaluate not only the character but also magnitude of developmental and growth changes.

## MATERIAL AND METHODS

X-ray films of the head from 27 healthy boys and 29 girls aged 4–6 years and 37 healthy men and 35 women, age 18–30 years were used for the study. The mean age of the boys was 5 years and 2 months, and 4 years and 11 months in the girls. The mean age of the men was 23 years, 11 months, and 20 years and 4 months in the women. Individuals were selected at random and the groups comprised only subjects of Czech nationality. The X-ray films of the children were obtained in 1967–9 during authorized investigations in Prague nursery schools and with the consent of the parents. Only subjects were included who were not subjected to any orthodontic treatment, with a clinically acceptable occlusion and without apparent facial disharmony. All still had their deciduous incisors. The adult probands were volunteers from among university students and patients hospitalized on account of minor injuries. The intermaxillary relations were not rigorously checked but subjects with a marked facial disharmony, reverse occlusion or those with a history of major orthodontic treatment were not included.

X-ray films were taken under standard conditions during centric occlusion with the proband's head fixed in a cephalostat (focus-film distance = 400 cm, object-film distance = 30 cm, enlargement 8.1%). Anteroposterior X-ray films were made with the head inclined caudally about 15° from the Frankfurt horizontal when the dense shadows of the pyramids are projected into the orbits and do no interfere with the investigated structures. The resulting AP craniogram is thus visualized under this angle. In lateral projections the inclination of the head is not important, the films are superimposed according to the plane of the anterior base of the skull. Craniometric points and reference lines used for evaluation of the films are illustrated in *Figures 1–3*. In the lateral projection, in case of double contours, the midpoint between the two sides was used. The assessed angles are described by three-symbol abbreviations (e.g. the angle of the base N-S-Ba) or as a fraction of the reference lines which form the given angle (e.g. the gonial angle ML/RL). Perpendicular distances of the point from the reference line are described e.g. as Pmp-NSL and the proportional data e.g. as N-Sp%N-Gn (height of upper face N-Sp in percent of total facial height N-Gn). Maxillary overjet (Is-Ii) was measured between the edges of the upper and lower incisors parallel to the occlusal plane OL. The prominence of the upper lip was assessed as the difference of the distances of points Ls and Li from the line passing through the "soft" nasion (N') and "soft" pogonion (Pg').

On the AP projection the mediosagittal plane (MSL) was constructed using the method described in a previous study (Šmahel, Brejcha 1983). For this projection only the widths are presented with two exceptions (Zy-Go and Sor-Or), while the vertical dimensions are influenced by the inclination of the head and were adequately defined from the lateral projection. For construction of the AP craniograms the perpendicular distances of all points from the mediosagittal (MSL) and horizontal (HL) lines were assessed. Some parameters of the lateral projection were also measured only for the construction of the resulting craniogram and they are not included in the tables. As for characteristics of the soft profile, only selected signs are presented. To make the drawings more illustrative the soft profile is not indicated on the craniograms.





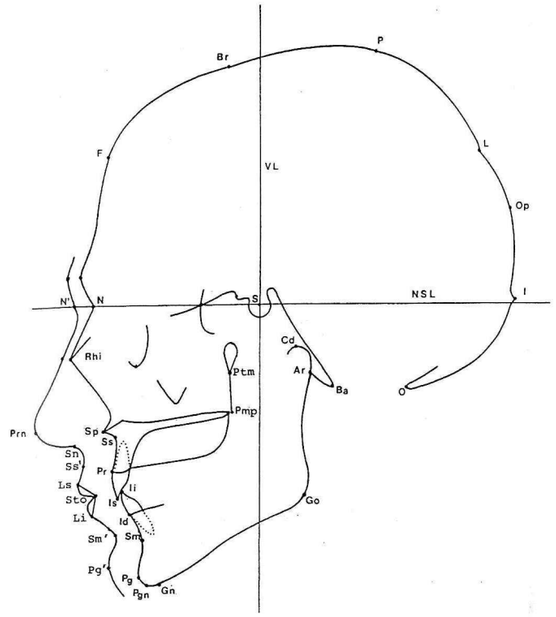


FIGURE 1. Cephalometric points used for the assessment of lateral X-ray films: Ar (*articulare*) – intersection of the inferior contour of the posterior cranial base and posterior contour of the ramus, Ba (*basion*) – most posteroinferior point on the *clivus*, Br (*bregma*) – intersection of the coronal suture and *lamina externa* of the cranial vault, Cd (*condylion*) – most superior point on the condylar head, F (*frontale*) – intersection of the perpendicular to the dimension N-Br through its midpoint and *lamina externa* of the cranial vault, Gn (*gnathion*) – lowest point of the mandibular symphysis, Go (*gonion*) – point on the angle of the mandible determined by the axis of ML/RL angle, I (*inion*) – top of the *protuberantia occipitalis externa*, Id (*infradentale*) – point of gingival contact with lower central incisor, Ii (*incision inferius*) – incisal tip of the lower central incisor, Is (*incision superius*) – incisal tip of the upper central incisor, L (*lambda*) – intersection of the lambdoid suture and *lamina externa* of the cranial vault, Li (*labrale inferius*) – margin of the vermilion of the lower lip, Ls (*labrale superius*) – margin of the vermilion of the upper lip, N (*nasion*) – most anterior point on the frontonasal suture, N'(soft *nasion*) – intersection between NSL and soft profile contour, O (*opisthion*) – most posterior point of the *foramen magnum*, Op (*opisthocranion*) – point on the surface of the cranial vault farthest from *nasion*, P (*parietale*) – intersection of the perpendicuar to the dimension Br-L through its midpoint and *lamina externa* of the cranial vault, Pg (*pogonion*) – most anterior point on the bony chin, Pg' (soft *pogonion*) – most anterior point on the soft tissue chin, Pgn (*prognathion*) – point on the mandibular symphysis farthest from Cd, Pmp (*pterygomaxillare palatinum*) – intersection of palatal line PL and *fissura pterygomaxillaris*, Pr (*prosthion*) – point of gingival contact with upper central incisor, Prn (*pronasale*) – point on the top of *apex nasi*, Ptm (*pterygomaxillare*) – most inferior point of *fossa pterygopalatina*, Rhi (*rhinion*) – most anteroinferior point on the nasal bone, S (*sella*) – center of *sella turcica*, Sm (*supramentale*) – deepest point on the anterior contour of the mandibular symphysis, Sm' (soft *supramentale*) – deepest point on the soft contour of the lower jaw, Sn (*subnasale*) – point at which *columella* merges with upper lip, Sp (*spinale*) – tip of anterior nasal spine, Ss (*subspinale*) – deepest point of the subspinal concavity, Ss' (soft *subspinale*) – deepest point of the upper lip, Sto (*stomion*) – point of contact of the upper and lower lip.

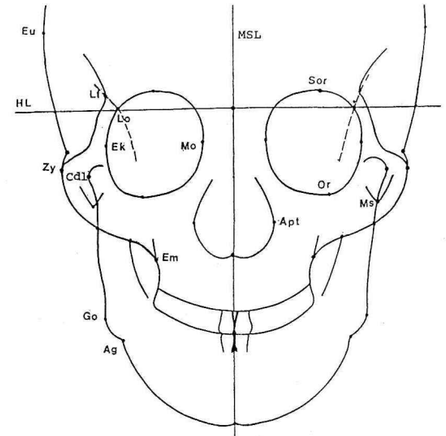


FIGURE 2. Cephalometric points used for the assessment of anteroposterior films: Ag (*antegonion*) – highest point in the antegonial notch, Apt (*apertion*) – most lateral point of the nasal cavity, Cdl (*condylion laterale*) – most lateral point on the condylar head, Ek (*ectokonchion*) – most lateral point of the orbital orifice, Em (*ectomaxillare*) – intersection of lateral contour of upper alveolar process and *crista zygomaticoalveolaris*, Eu (*euryon*) – most lateral point of the cranial vault, Go (*gonion*) – most lateral point of the mandibular angle, Lf (*laterofrontale*) – point of intersection between lateral margin of the *ala major* and *linea temporalis* on the frontal bone, Lo (*lateroorbitale*) – point of intersection between lateral margin of the *ala major* and contour of the *orbita*, Mo (*medioorbitale*) – most medial point of the orbital orifice, Ms (*mastoideale*) – top of the *proc. mastoideus*, Or (*orbitale*) – lowest point of the orbital orifice, Sor (*supraorbitale*) – highest point of the roof of the orbit, Zy (*zygion*) most lateral point on the zygomatic bone; MSL – mediosagittal line (see text), HL – horizontal line – perpendicular to MSL through left point Lo.

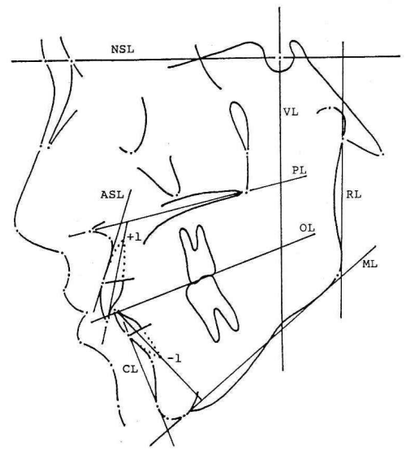


FIGURE 3. Reference lines plotted on lateral X-ray films: NSL = line through N and S, VL = perpendicular to NSL through S, PL = line through Sp and posterior nasal spine, CL = line through Pg and Id, ML = tangent to the mandibular body through Gn, RL = tangent to the mandibular ramus through Ar, OL = line through midpoint between tips of the upper and lower incisors and through the posterior cusp of the first lower molar, ASL = tangent to the maxillar alveolar process through Pr, +1 = axis of the upper central incisors, –1 = axis of the lower central incisors.

TABLE 1. Roentgencephalometric characteristics of linear parameters in Czech males at the age of 5 years and in adult age. Increments in percent of mean values at 5 years (incr %) and values at 5 years in percent of the size in adults (% adults).

| Variable | | 5 years | | Adults | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | t | incr % | % adults |
| **Neurocranium** | | | | | | | | |
| N-Op | | 162.74 | 7.24 | 177.04 | 4.62 | 9.64 | 8.79 | 91.74 |
| Ba-Br | | 131.69 | 4.87 | 141.28 | 4.82 | 7.83 | 7.28 | 93.21 |
| Ba-L | | 109.01 | 5.85 | 115.57 | 4.32 | 5.16 | 6.02 | 94.32 |
| S-P | | 113.98 | 5.57 | 116.34 | 4.18 | 1.94 | 2.07 | 97.97 |
| **Cranial base** | | | | | | | | |
| N-S | | 60.99 | 2.23 | 69.05 | 2.97 | 11.86 | 13.22 | 88.33 |
| S-Ba | | 35.95 | 2.48 | 44.77 | 3.18 | 11.99 | 24.53 | 80.30 |
| **Face** | | | | | | | | |
| N-Rhi | | 17.88 | 2.08 | 23.32 | 3.25 | 7.62 | 30.43 | 76.67 |
| N-Sp | | 40.34 | 2.69 | 52.95 | 3.39 | 15.99 | 31.26 | 76.19 |
| N-Pr | | 56.87 | 3.71 | 69.35 | 3.61 | 13.50 | 21.94 | 82.00 |
| N-Gn | | 92.78 | 5.28 | 119.53 | 5.79 | 18.93 | 28.83 | 77.62 |
| Sp-Is | | 23.12 | 1.68 | 28.30 | 3.31 | 7.45 | 22.40 | 81.70 |
| Pr-Id | | 12.65 | 2.14 | 19.57 | 2.15 | 12.74 | 54.70 | 64.64 |
| Ii-Gn | | 31.51 | 1.74 | 42.13 | 2.80 | 17.39 | 33.70 | 74.79 |
| Id-Gn | | 24.99 | 1.98 | 31.98 | 2.60 | 11.55 | 27.61 | 78.36 |
| Sp-Pg | | 49.16. | 4.15 | 61.70 | 5.98 | 9.37 | 25.51 | 79.68 |
| S-Go | | 58.39 | 3.65 | 81.42 | 4.84 | 20.77 | 39.44 | 71.71 |
| Cd-Go | | 43.29 | 2.53 | 61.67 | 4.17 | 20.31 | 42.46 | 70.20 |
| Pgn-Go | | 54.00 | 3.51 | 72.90 | 4.03 | 19.54 | 35.00 | 74.07 |
| Ss-Pmp | | 39.61 | 1.95 | 48.30 | 2.69 | 14.26 | 21.94 | 82.01 |
| Pmp-Ba | | 39.61 | 1.98 | 44.84 | 3.03 | 7.82 | 13.20 | 88.34 |
| Pmp-NSL | | 34.93 | 2.16 | 45.08 | 2.72 | 16.04 | 29.06 | 77.48 |
| Pr-PL | | 16.37 | 1.91 | 16.49 | 3.06 | 0.18 | 0.73 | 99.27 |
| **Soft Profile** | | | | | | | | |
| N'-Prn | | 38.42 | 3.08 | 53.84 | 3.78 | 17.39 | 40.14 | 71.36 |
| N'-Sn | | 44.34 | 2.90 | 58.97 | 3.29 | 18.45 | 33.00 | 75.19 |
| N'-Sto | | 62.44 | 3.42 | 79.80 | 3.74 | 19.00 | 27.80 | 78.25 |
| N'-Pg' | | 85.64 | 4.90 | 110.68 | 4.88 | 20.24 | 29.24 | 77.38 |
| Prn-Sn | | 12.88 | 1.13 | 18.54 | 1.83 | 14.20 | 43.94 | 69.47 |
| Prn-Sp | | 18.75 | 1.30 | 29.23 | 2.33 | 21.07 | 55.89 | 64.15 |
| Sn-Sto | | 18.80 | 1.73 | 22.31 | 2.67 | 5.97 | 18.67 | 84.27 |
| **A-P Projection** | | | | | | | | |
| Eu-Eu | | 142.10 | 4.87 | 150.17 | 5.59 | 6.02 | 5.68 | 94.63 |
| Lf-Lf | | 97.00 | 2.67 | 101.26 | 4.01 | 4.79 | 4.39 | 95.79 |
| Lo-Lo | | 87.92 | 2.49 | 93.97 | 3.59 | 7.53 | 6.88 | 93.56 |
| Ms-Ms | | 96.51 | 5.16 | 110.08 | 4.99 | 10.59 | 14.06 | 87.67 |
| Zy-Zy | | 111.70 | 3.22 | 135.32 | 4.37 | 23.75 | 21.15 | 82.55 |
| Mo-Mo | | 21.63 | 1.91 | 24.84 | 2.29 | 5.93 | 14.84 | 87.08 |
| Ek-Ek | | 89.37 | 2.63 | 101.40 | 3.77 | 14.23 | 13.46 | 88.14 |
| Mo-Ek | dx | 34.13 | 0.92 | 38.47 | 1.90 | 10.95 | 12.72 | 88.72 |
| | sin | 33.78 | 1.33 | 38.25 | 1.91 | 10.44 | 13.23 | 88.31 |
| Em-Em | | 56.03 | 2.53 | 63.31 | 3.80 | 8.64 | 12.99 | 88.50 |
| Apt-Apt | | 24.62 | 1.48 | 32.26 | 2.59 | 13.76 | 31.03 | 76.32 |
| Go-Go | | 79.37 | 3.92 | 103.38 | 7.01 | 16.04 | 30.25 | 76.78 |
| Ag-Ag | | 73.12 | 3.10 | 90.76 | 5.79 | 14.38 | 24.12 | 80.56 |
| Cdl-Cdl | | 97.17 | 3.47 | 117.19 | 5.34 | 17.02 | 20.60 | 82.92 |
| Zy-Go | dx | 45.63 | 4.24 | 62.66 | 5.38 | 13.64 | 37.32 | 72.82 |
| | sin | 45.15 | 4.43 | 62.20 | 5.61 | 13.08 | 37.73 | 72.59 |
| Sor-Or | dx | 36.50 | 1.91 | 40.14 | 2.45 | 6.42 | 9.97 | 90.93 |
| | sin | 36.61 | 1.76 | 40.20 | 2.27 | 6.85 | 9.81 | 91.07 |

t = results of t-tests of the differences between the age of 5 years and values in adults; in all characteristics $p < 0.000$ but for S-P ($p = 0.057$) and Pr-PL ($p = 0.858$).





TABLE 2. Roentgencephalometric characteristics of linear parameters in Czech females at the age of 5 years and in adult age. Increments in percent of mean values at 5 years (incr %) and values at 5 years in percent of the size in adults (% adults).

| Variable | | 5 years | | Adults | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | t | incr % | % adults |
| **Neurocranium** | | | | | | | | |
| N-Op | | 157.80 | 5.28 | 171.00 | 8.21 | 7.47 | 8.37 | 92.28 |
| Ba-Br | | 126.08 | 5.03 | 134.97 | 5.80 | 6.48 | 7.05 | 93.41 |
| Ba-L | | 106.84 | 5.45 | 112.00 | 6.27 | 3.48 | 4.83 | 95.39 |
| S-P | | 110.51 | 4.68 | 112.92 | 5.92 | 1.78 | 2.18 | 97.87 |
| **Cranial base** | | | | | | | | |
| N-S | | 58.19 | 2.52 | 66.59 | 3.21 | 11.46 | 14.44 | 87.39 |
| S-Ba | | 33.94 | 1.86 | 41.41 | 2.71 | 12.58 | 22.01 | 81.96 |
| **Face** | | | | | | | | |
| N-Rhi | | 17.33 | 2.56 | 22.80 | 4.13 | 6.21 | 31.56 | 76.01 |
| N-Sp | | 38.27 | 2.33 | 49.11 | 3.27 | 14.97 | 28.32 | 77.93 |
| N-Pr | | 54.57 | 2.78 | 64.60 | 4.72 | 10.08 | 18.38 | 84.47 |
| N-Gn | | 88.83 | 3.70 | 109.66 | 7.63 | 13.44 | 23.45 | 81.00 |
| Sp-Is | | 22.48 | 1.44 | 26.94 | 3.24 | 6.86 | 19.84 | 83.44 |
| Pr-Id | | 11.28 | 1.38 | 18.18 | 1.93 | 16.13 | 61.17 | 62.05 |
| Ii-Gn | | 30.60 | 1.42 | 38.15 | 3.10 | 12.09 | 24.67 | 80.21 |
| Id-Gn | | 24.83 | 1.44 | 28.45 | 2.86 | 6.19 | 14.58 | 87.28 |
| Sp-Pg | | 47.26 | 3.00 | 56.19 | 8.77 | 5.23 | 18.90 | 84.11 |
| S-Go | | 55.19 | 2.65 | 74.21 | 5.81 | 16.27 | 34.46 | 74.37 |
| Cd-Go | | 40.56 | 2.74 | 55.26 | 4.87 | 14.46 | 36.24 | 73.40 |
| Pgn-Go | | 53.45 | 3.03 | 69.38 | 5.10 | 14.78 | 29.80 | 77.04 |
| Ss-Pmp | | 38.55 | 1.66 | 44.22 | 2.60 | 10.15 | 14.71 | 87.18 |
| Pmp-Ba | | 38.42 | 2.30 | 43.63 | 3.23 | 7.29 | 13.56 | 88.06 |
| Pmp-NSL | | 33.33 | 1.83 | 43.11 | 2.87 | 15.86 | 29.34 | 77.31 |
| Pr-PL | | 16.00 | 1.17 | 16.07 | 2.40 | 0.14 | 0.44 | 99.56 |
| **Soft Profile** | | | | | | | | |
| N'-Prn | | 36.82 | 2.73 | 50.27 | 4.08 | 15.15 | 36.53 | 73.24 |
| N'-Sn | | 42.40 | 2.49 | 55.26 | 3.76 | 15.76 | 30.33 | 76.73 |
| N'-Sto | | 59.19 | 2.60 | 73.75 | 4.61 | 15.12 | 24.60 | 80.26 |
| N'-Pg' | | 83.52 | 4.02 | 102.61 | 6.79 | 13.32 | 22.86 | 81.40 |
| Prn-Sn | | 12.67 | 1.18 | 18.07 | 1.57 | 15.28 | 42.62 | 70.12 |
| Prn-Sp | | 17.65 | 1.55 | 25.70 | 2.62 | 14.56 | 45.61 | 68.68 |
| Sn-Sto | | 17.45 | 1.60 | 19.79 | 2.99 | 3.79 | 13.41 | 88.18 |
| **A-P Projection** | | | | | | | | |
| Eu-Eu | | 137.36 | 5.36 | 143.17 | 5.10 | 4.43 | 4.23 | 95.94 |
| Lf-Lf | | 91.41 | 3.76 | 97.78 | 4.44 | 6.12 | 6.97 | 93.49 |
| Lo-Lo | | 83.21 | 3.24 | 90.15 | 4.05 | 7.46 | 8.34 | 92.30 |
| Ms-Ms | | 92.80 | 6.01 | 103.20 | 4.58 | 7.85 | 11.21 | 89.92 |
| Zy-Zy | | 106.17 | 4.34 | 127.06 | 4.67 | 18.40 | 19.68 | 83.56 |
| Mo-Mo | | 20.41 | 2.03 | 24.59 | 2.06 | 8.13 | 20.48 | 83.00 |
| Ek-Ek | | 84.97 | 3.46 | 95.83 | 3.67 | 12.09 | 12.78 | 88.67 |
| Mo-Ek | dx | 32.62 | 1.10 | 35.85 | 1.29 | 10.65 | 9.90 | 90.99 |
| | sin | 32.38 | 1.21 | 35.61 | 1.09 | 11.23 | 9.98 | 90.93 |
| Em-Em | | 53.61 | 2.62 | 60.12 | 3.73 | 7.92 | 12.14 | 89.17 |
| Apt-Apt | | 23.75 | 1.31 | 30.47 | 2.74 | 12.10 | 28.29 | 77.95 |
| Go-Go | | 76.74 | 4.57 | 94.17 | 4.59 | 15.15 | 22.71 | 81.49 |
| Ag-Ag | | 70.70 | 3.87 | 84.18 | 4.03 | 13.56 | 19.07 | 83.99 |
| Cdl-Cdl | | 92.89 | 3.43 | 109.46 | 4.62 | 16.00 | 17.83 | 84.86 |
| Zy-Go | dx | 43.35 | 2.70 | 56.27 | 5.32 | 11.86 | 29.80 | 77.04 |
| | sin | 42.81 | 2.75 | 54.87 | 4.62 | 12.35 | 28.17 | 78.02 |
| Sor-Or | dx | 35.12 | 1.54 | 37.72 | 1.57 | 6.65 | 7.40 | 93.11 |
| | sin | 34.99 | 1.44 | 37.77 | 1.62 | 7.18 | 7.95 | 92.64 |

t = results of t-tests of the differences between the age of 5 years and values in adults; in all characteristics $p < 0.000$ but for S-P ($p = 0.080$) and Pr-PL ($p = 0.886$).

TABLE 3. Roentgencephalometric characteristics of parameters of shape and position in Czech males at the age of 5 years and in adult age; differences between the age of 5 years and adult age (d) and the results of t-tests.

| Variable | 5 years | | Adults | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | d | t | p |
| **Neurocranium** | | | | | | | |
| S-N-F | 94.56 | 4.02 | 85.80 | 3.57 | –8.76 | 9.12 | 0.000 |
| N-S-Br | 77.19 | 3.48 | 81.60 | 4.47 | 4.41 | 4.21 | 0.000 |
| N-S-L | 141.59 | 4.48 | 144.17 | 5.54 | 2.58 | 1.97 | 0.054NS |
| Ba-O/NSL | 1.07 | 5.31 | –3.57 | 6.00 | –4.64 | 3.17 | 0.002 |
| **Cranial base** | | | | | | | |
| N-S-Ba | 133.79 | 4.75 | 132.59 | 5.62 | –1.20 | 0.99 | 0.352NS |
| N-S-Cd | 128.32 | 7.95 | 129.77 | 8.50 | 1.45 | 0.76 | 0.492NS |
| **Face** | | | | | | | |
| N-S-Go | 99.95 | 4.07 | 102.19 | 4.22 | 2.24 | 2.33 | 0.024 |
| N-S-Pgn | 68.85 | 3.31 | 68.40 | 4.34 | –0.45 | 0.50 | 0.668NS |
| S-N-Rhi | 100.68 | 5.51 | 115.48 | 6.80 | 14.80 | 10.29 | 0.000 |
| S-N-Ss | 78.86 | 3.75 | 80.81 | 4.13 | 1.95 | 2.12 | 0.039 |
| S-N-Pr | 79.06 | 3.77 | 82.94 | 4.27 | 3.88 | 4.14 | 0.000 |
| S-N-Id | 75.99 | 3.69 | 79.98 | 4.05 | 3.99 | 4.42 | 0.000 |
| S-N-Sm | 74.69 | 3.28 | 78.32 | 4.06 | 3.63 | 4.23 | 0.000 |
| S-N-Pg | 74.52 | 3.25 | 79.88 | 4.14 | 5.36 | 6.19 | 0.000 |
| Ss-N-Sm | 4.18 | 2.21 | 2.49 | 1.72 | 1.69 | 3.44 | 0.001 |
| Pr-N-Id | 3.06 | 1.29 | 2.96 | 1.35 | –0.10 | 0.30 | 0.767NS |
| N-Ss-Pg | 171.56 | 4.36 | 178.08 | 5.06 | 6.52 | 5.39 | 0.000 |
| PL/NSL | 6.77 | 2.70 | 8.35 | 3.96 | 1.58 | 2.00 | 0.053NS |
| OL/NSL | 19.26 | 3.40 | 12.96 | 4.74 | –6.30 | 6.58 | 0.000 |
| ML/NSL | 35.07 | 4.08 | 29.86 | 6.86 | –5.21 | 3.97 | 0.000 |
| ML/RL | 130.64 | 5.38 | 120.89 | 7.01 | –9.75 | 6.72 | 0.000 |
| CL/ML | 75.53 | 3.97 | 71.00 | 5.79 | –4.53 | 3.93 | 0.000 |
| RL/NSL | 84.43 | 5.02 | 88.98 | 4.77 | 4.55 | 3.10 | 0.000 |
| PL/ML | 28.30 | 3.96 | 21.62 | 6.78 | –6.68 | 5.18 | 0.000 |
| ASL/PL | 90.18 | 8.89 | 109.41 | 6.69 | 19.23 | 10.51 | 0.000 |
| +1/PL | 94.31 | 8.35 | 107.85 | 6.48 | 13.54 | 7.80 | 0.000 |
| –1/ML | 85.95 | 5.25 | 94.87 | 7.23 | 8.92 | 6.08 | 0.000 |
| +1/–1 | 148.70 | 9.33 | 135.65 | 8.64 | –13.05 | 6.24 | 0.000 |
| Cd-NSL | 14.24 | 1.92 | 17.95 | 3.92 | 3.71 | 4.53 | 0.000 |
| Ar-VL | 15.20 | 2.55 | 20.89 | 3.10 | 5.69 | 7.80 | 0.000 |
| Ptm-VL | 12.22 | 1.59 | 12.41 | 2.21 | 0.19 | 0.38 | 0.705NS |
| Pmp-VL | 13.40 | 2.17 | 13.69 | 3.21 | 0.29 | 0.41 | 0.686NS |
| Is-Ii | 1.87 | 1.26 | 2.53 | 1.21 | 0.66 | 2.12 | 0.038 |
| **Soft profile** | | | | | | | |
| S-N'-Ss' | 83.47 | 3.75 | 87.12 | 4.04 | 3.65 | 4.03 | 0.000 |
| S-N'-Sm' | 76.21 | 3.35 | 80.09 | 4.12 | 3.88 | 4.44 | 0.000 |
| S-N'-Pg' | 77.21 | 3.10 | 82.03 | 4.15 | 4.82 | 5.66 | 0.000 |
| N'-Prn-Pg' | 140.02 | 4.01 | 133.61 | 5.23 | –6.41 | 5.91 | 0.000 |
| N'-Sn-Pg' | 164.91 | 4.66 | 163.88 | 5.64 | –1.03 | 0.86 | 0.427NS |
| Ss'-N'-Sm' | 7.26 | 1.84 | 7.20 | 1.52 | –0.06 | 0.16 | 0.921NS |
| Ls+Li | 3.81 | 1.51 | 4.09 | 1.52 | 0.28 | 0.73 | 0.468NS |
| **Proportions** | | | | | | | |
| S-Go%N-Gn | 62.99 | 3.19 | 68.16 | 4.68 | 5.17 | 5.55 | 0.000 |
| N-Sp%N-Gn | 43.50 | 1.95 | 44.34 | 2.69 | 0.84 | 1.54 | 0.138NS |

NS = not significant





TABLE 4. Roentgencephalometric characteristics of parameters of shape and position in Czech females at the age of 5 years and in adult age; differences between the age of 5 years and adult age (d) and the results of t-tests.

| Variable | 5 years | | Adults | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | d | t | p |
| **Neurocranium** | | | | | | | |
| S-N-F | 93.90 | 3.78 | 87.75 | 3.14 | –6.15 | 7.24 | 0.000 |
| N-S-Br | 77.73 | 2.77 | 80.25 | 3.43 | 2.52 | 3.24 | 0.002 |
| N-S-L | 142.37 | 4.58 | 146.14 | 4.56 | 3.77 | 3.34 | 0.001 |
| Ba-O/NSL | 4.13 | 4.40 | 1.72 | 5.27 | –2.41 | 1.99 | 0.051NS |
| **Cranial base** | | | | | | | |
| N-S-Ba | 133.80 | 4.28 | 131.00 | 5.75 | –2.80 | 2.30 | 0.025 |
| N-S-Cd | 127.59 | 7.86 | 128.63 | 6.86 | 1.04 | 0.59 | 0.606NS |
| **Face** | | | | | | | |
| N-S-Go | 99.55 | 3.00 | 101.63 | 3.99 | 2.08 | 2.46 | 0.017 |
| N-S-Pgn | 67.92 | 3.40 | 66.51 | 4.62 | –1.41 | 1.45 | 0.165NS |
| S-N-Rhi | 104.74 | 4.77 | 115.39 | 6.22 | 10.65 | 8.04 | 0.000 |
| S-N-Ss | 80.98 | 2.79 | 81.01 | 3.86 | 0.03 | 0.04 | 0.994NS |
| S-N-Pr | 80.99 | 3.22 | 84.09 | 3.89 | 3.10 | 3.62 | 0.000 |
| S-N-Id | 77.74 | 3.09 | 80.53 | 3.74 | 2.79 | 3.40 | 0.001 |
| S-N-Sm | 76.46 | 3.12 | 78.73 | 3.76 | 2.27 | 2.74 | 0.008 |
| S-N-Pg | 76.02 | 3.21 | 80.25 | 4.04 | 4.23 | 4.86 | 0.000 |
| Ss-N-Sm | 4.52 | 1.83 | 2.28 | 1.54 | 2.24 | 5.32 | 0.000 |
| Pr-N-Id | 3.25 | 1.26 | 3.56 | 1.76 | 0.31 | 0.79 | 0.430NS |
| N-Ss-Pg | 170.47 | 3.80 | 178.70 | 5.63 | 8.23 | 6.70 | 0.000 |
| PL/NSL | 6.57 | 2.49 | 6.75 | 3.14 | 0.18 | 0.27 | 0.838NS |
| OL/NSL | 18.75 | 3.17 | 12.42 | 4.57 | –6.33 | 6.74 | 0.000 |
| ML/NSL | 35.69 | 4.97 | 28.98 | 7.25 | –6.71 | 4.52 | 0.000 |
| ML/RL | 130.76 | 5.33 | 120.17 | 7.22 | –10.59 | 6.98 | 0.000 |
| CL/ML | 74.10 | 4.94 | 71.20 | 6.45 | –2.90 | 2.12 | 0.040 |
| RL/NSL | 84.93 | 3.85 | 88.82 | 4.14 | 3.89 | 4.06 | 0.000 |
| PL/ML | 29.13 | 4.84 | 22.23 | 7.05 | –6.90 | 4.77 | 0.000 |
| ASL/PL | 92.17 | 5.77 | 113.41 | 7.67 | 21.24 | 13.10 | 0.000 |
| +1/PL | 95.51 | 5.18 | 108.73 | 6.52 | 13.22 | 9.39 | 0.000 |
| –1/ML | 83.25 | 6.20 | 94.53 | 8.72 | 11.28 | 6.24 | 0.000 |
| +1/–1 | 151.46 | 5.93 | 134.50 | 8.46 | –16.96 | 9.71 | 0.000 |
| Cd-NSL | 13.90 | 2.28 | 17.42 | 2.89 | 3.52 | 5.33 | 0.000 |
| Ar-VL | 13.74 | 2.01 | 18.34 | 3.09 | 4.60 | 6.89 | 0.000 |
| Ptm-VL | 12.31 | 1.88 | 13.50 | 2.62 | 1.19 | 2.05 | 0.045 |
| Pmp-VL | 13.88 | 2.03 | 14.76 | 3.26 | 0.88 | 1.26 | 0.211NS |
| Is-Ii | 2.12 | 1.43 | 3.51 | 1.17 | 1.39 | 4.28 | 0.000 |
| **Soft profile** | | | | | | | |
| S-N'-Ss' | 85.18 | 2.97 | 87.15 | 3.89 | 1.97 | 2.39 | 0.020 |
| S-N'-Sm' | 77.55 | 2.68 | 80.52 | 3.53 | 2.97 | 3.73 | 0.000 |
| S-N'-Pg' | 78.51 | 2.67 | 82.65 | 3.63 | 4.14 | 5.44 | 0.000 |
| N'-Prn-Pg' | 138.99 | 4.74 | 133.45 | 4.61 | –5.54 | 4.95 | 0.000 |
| N'-Sn-Pg' | 164.56 | 4.61 | 164.36 | 7.17 | –0.20 | 0.14 | 0.939NS |
| Ss'-N'-Sm' | 7.62 | 1.89 | 6.63 | 2.16 | –0.99 | 2.03 | 0.049 |
| Ls+Li | 4.02 | 1.64 | 3.67 | 2.02 | 0.35 | 0.75 | 0.456NS |
| **Proportions** | | | | | | | |
| S-Go%N-Gn | 62.20 | 3.16 | 67.86 | 5.48 | 5.66 | 5.30 | 0.000 |
| N-Sp%N-Gn | 43.07 | 1.92 | 44.86 | 2.50 | 1.79 | 3.36 | 0.001 |

NS = not significant

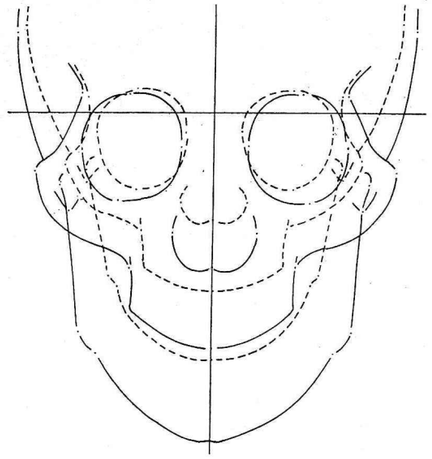

FIGURE 4. Anteroposterior craniograms in males at the age of 5 years (dashed line) and in adult age (full line).

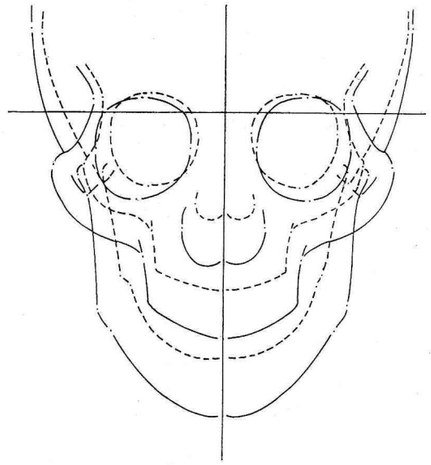

FIGURE 5. Anteroposterior craniograms in females at the age of 5 years (dashed line) and in adult age (full line).

The craniometric points and reference lines were indicated on all films only by the main author, in the assessment of defined areas the co-authors participated. Measurement of the face from a lateral projection was made with a digitizer, measurements of the characteristics of the neurocranium and AP projection were made by hand since software was not available. Some parameters of lateral projection were measured previously by hand and the comparison with the results of measurements with a digitizer revealed negligible differences. All linear dimensions were corrected with regard to enlargement and the results thus are real values (norms).

Repeated measurements on a digitiser were made on 25 subjects selected at random and coefficients of reliability were calculated from the differences. In all parameters the coefficients were higher than 95% (Šabík 1996). The previous evaluation of reliability of the method gave similar results and confirms the high reliability of measurements (Šmahel, Škvařilová 1988, Šmahel *et al.* 1994). A greater error of measurements (5–10%) was recorded only in signs comprising the condylion (Cd) point and in the inclination of the upper alveolar process (ASL/PL) and angle N-S-L.

From the assessed data basic statistical parameters were calculated and differences in the magnitude of characteristics between children and adults as well as intersexual differences were tested by the non-paired two-sided t-test. Because the highly significant enlargement of linear skull dimensions from childhood to adult age is natural, the size of this enlargement was expressed as a percentage in two ways:

1. as the size of the characteristic in the child skull expressed in percent of the final size in adult age (i.e. the percentage of the final size attained at the age of 5 years);
2. the difference between the size of the sign in childhood and in adult age ("increment") as a percentage of the initial size of the characteristic at the age of 5 years (i.e. by what percentage of its size the characteristic will yet grow).

This procedure makes mutual comparison of parameters of various size possible. In studies of intersexual differences the size of the female skull was expressed in terms of percent of the male skull.

## RESULTS

**Amount of growth:** The basic statistical characteristics of linear parameters are presented in *Tables 1–2.*

From the differences in magnitude of the investigated parameters at the age of 5 years and in adult age it is obvious that at the age of 5 years the neurocranium reaches more than 90% of its final size. It will grow the most in length (N-Op, 8.5%), less in height (Ba-Br, Ba-L, 5–7%) and width (Eu-Eu, Lf-Lf, 4–7%) and the increase of the vault height will be the smallest (S-P, 2%). In the latter parameter the difference between the 5-year-old skull and the adult skull is not significant. The intersexual differences in the amount of growth of the neurocranium are small (under 2.5%, *Tables 1 vs. 2*) .

The skull base will grow during that period in the length of the presellar portion (N-S) by 13–14% (intersexual difference) and in the postsellar part (S-Ba) by 22–25%. To a similar extent as the anterior base, the depth of the skeletal framework of the nasopharynx (Pmp-Ba, 13%) will increase as well as the bimastoid breadth (Ms-Ms, 11–14%), while the width of the base in the area of the *alae magnae* of the sphenoid bone increases little, similarly to the neurocranium (Lo-Lo, 7–8%).





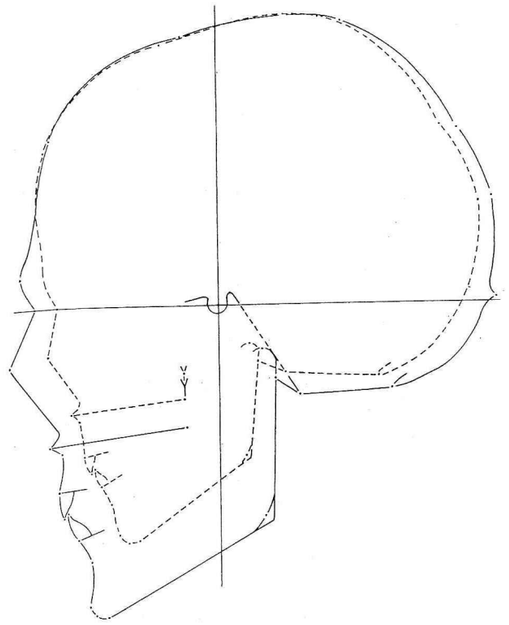

FIGURE 6. Lateral craniograms in males at the age of 5 years (dashed line) and in adult age (full line).

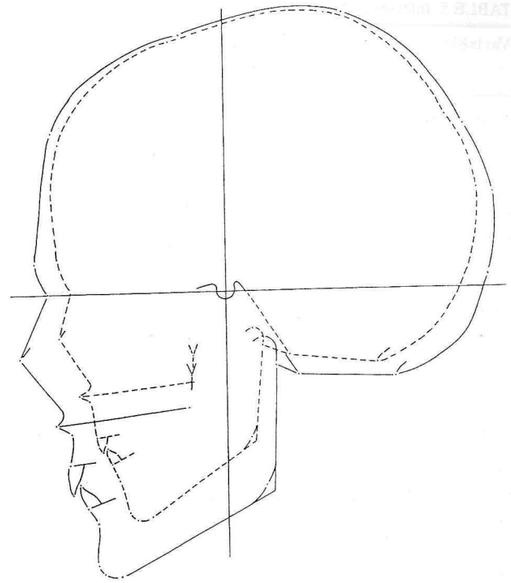

FIGURE 7. Lateral craniograms in females at the age of 5 years (dashed line) and in adult age (full line).

The face grows most in a vertical direction, the length of the nasal bones (N-Rhi) by 30% (males) and by 32% (females), the upper face (N-Sp) by 31% and 28% respectively, the lower face (Sp-Pg) by 25% and 19% respectively, the height of the mandibular body (Id-Gn) by 28% and 25% and the total facial height (N-Gn) by 29% and 23%. The face grows less in depth (Ss-Pmp, 22% and 15%). The height of the alveolar process (Pr-PL) does not grow any further and this is reflected in a smaller increase in maxillary height (N-Pr, 22% and 18%). The greatest growth occurs, however, in the lower jaw, particularly in the ramus (Cd-Go, 42% and 36%; body Pgn-Go, 35% and 30%). Subsequently the posterior height of the face (S-Go, 39% and 34%) increases more than the anterior one (N-Gn 29 and 23%) and this leads to developmental anteriorotation of the face. This is confirmed by the ratio of the two heights (S-Go%N-Go) which increases from 62–63% to 68% *(Tables 3–4).* The greatest increase occurs in conjunction with eruption of the permanent incisors in the anterior dental height (Pr-Id, 55% and 61%). With the exception of the length of the nasal bones, the growth is greater in males than in females. The vertical proportionality of the face (N-Sp%N-Gn) changed only insignificantly in males, in females a relative increase in the height of the upper face was found (*Tables 3–4*).

The anteroposterior projection also confirms a greater increase in the width of the mandible (Go-Go 30% and 23%, Ag-Ag 24% and 19%) than of the face (Zy-Zy, 21% and 20%) and of the bicondylar distance (Cdl-Cdl 21% and 18%). The growth is however slighter than in height characteristics. There is only a small increase (10–15%) in the intraocular distance (Mo-Mo, but in females 20%), the biorbital distance (Ek-Ek), the width of the upper dentoalveolar arch (Em-Em), and the height of the orbits (Sor-Or, 7–10%). On the contrary there is a great increase in the width of the nasal cavity (Apt-Apt 31% and 28%).

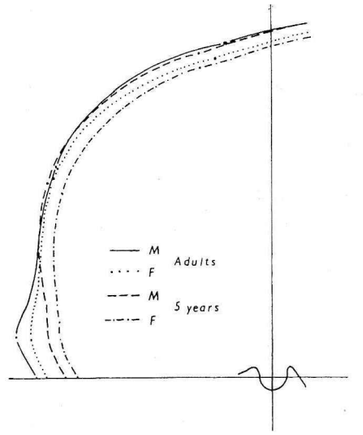


FIGURE 8. The profiles of frontal bone in males (M) and females (F) at the age of 5 years and in adults.

TABLE 5. Intersexual differences (d) in characteristics of size at the age of 5 years and in adults.

| Variable | | 5 years | | | Adults | | |
|---|---|---|---|---|---|---|---|
| | | d | t | p | d | t | p |
| **Neurocranium** | | | | | | | |
| N-Op | | 4.94 | 2.93 | 0.005 | 6.04 | 3.87 | 0.000 |
| Ba-Br | | 5.61 | 4.24 | 0.000 | 6.31 | 5.03 | 0.000 |
| Ba-L | | 2.17 | 1.44 | 0.156NS | 3.57 | 2.83 | 0.006 |
| S-P | | 3.47 | 2.53 | 0.014 | 3.42 | 2.84 | 0.006 |
| **Cranial base** | | | | | | | |
| N-S | | 2.80 | 4.39 | 0.000 | 2.46 | 3.38 | 0.001 |
| S-Ba | | 2.01 | 3.45 | 0.001 | 3.36 | 4.81 | 0.000 |
| **Face** | | | | | | | |
| N-Rhi | | 0.55 | 0.79 | 0.384NS | 0.52 | 0.60 | 0.553NS |
| N-Sp | | 2.07 | 3.08 | 0.003 | 3.84 | 4.89 | 0.000 |
| N-Pr | | 2.30 | 2.64 | 0.011 | 4.75 | 4.81 | 0.000 |
| N-Gn | | 3.94 | 3.26 | 0.002 | 9.87 | 6.20 | 0.000 |
| Sp-Is | | 0.64 | 1.53 | 0.131NS | 1.36 | 1.76 | 0.083NS |
| Pr-Id | | 1.37 | 2.87 | 0.006 | 1.39 | 2.88 | 0.005 |
| Ii-Gn | | 0.91 | 2.15 | 0.036 | 3.98 | 5.72 | 0.000 |
| Id-Gn | | 0.16 | 0.35 | 0.730NS | 3.44 | 5.34 | 0.000 |
| Sp-Pg | | 1.90 | 1.97 | 0.054NS | 5.51 | 3.13 | 0.003 |
| S-Go | | 3.20 | 3.77 | 0.000 | 7.21 | 5.73 | 0.000 |
| Cd-Go | | 2.73 | 3.86 | 0.000 | 6.41 | 6.01 | 0.000 |
| Pgn-Go | | 0.55 | 0.63 | 0.532NS | 3.52 | 3.26 | 0.002 |
| Ss-Pmp | | 1.06 | 2.20 | 0.032 | 4.08 | 6.54 | 0.000 |
| Pmp-Ba | | 1.19 | 2.07 | 0.043 | 1.21 | 1.64 | 0.105NS |
| Pmp-NSL | | 1.60 | 3.00 | 0.004 | 1.97 | 2.99 | 0.004 |
| Pr-PL | | 0.37 | 0.88 | 0.382NS | 0.42 | 0.65 | 0.521NS |
| **Soft Profile** | | | | | | | |
| N'-Prn | | 1.60 | 2.06 | 0.044 | 3.57 | 3.85 | 0.000 |
| N'-Sn | | 1.94 | 2.69 | 0.009 | 3.71 | 4.46 | 0.000 |
| N'-Sto | | 3.25 | 4.02 | 0.000 | 6.05 | 6.13 | 0.000 |
| N'-Pg' | | 2.12 | 1.78 | 0.081NS | 8.07 | 5.82 | 0.000 |
| Prn-Sn | | 0.21 | 0.68 | 0.500NS | 0.47 | 1.17 | 0.247NS |
| Prn-Sp | | 1.10 | 2.87 | 0.006 | 3.53 | 6.05 | 0.000 |
| Sn-Sto | | 1.35 | 3.03 | 0.004 | 2.52 | 3.78 | 0.000 |
| **A-P Projection** | | | | | | | |
| Eu-Eu | | 4.74 | 3.45 | 0.001 | 7.00 | 5.54 | 0.000 |
| Lf-Lf | | 5.59 | 6.37 | 0.000 | 3.48 | 3.49 | 0.000 |
| Lo-Lo | | 4.71 | 6.07 | 0.000 | 3.82 | 4.24 | 0.000 |
| Ms-Ms | | 3.71 | 2.47 | 0.017 | 6.88 | 6.08 | 0.000 |
| Zy-Zy | | 5.53 | 5.38 | 0.000 | 8.26 | 7.75 | 0.000 |
| Mo-Mo | | 1.22 | 2.31 | 0.025 | 0.25 | 0.49 | 0.628NS |
| Ek-Ek | | 4.40 | 5.33 | 0.000 | 5.57 | 6.35 | 0.000 |
| Mo-Ek | dx | 1.51 | 5.55 | 0.000 | 2.62 | 6.81 | 0.000 |
| | sin | 1.40 | 4.12 | 0.000 | 2.64 | 7.15 | 0.000 |
| Em-Em | | 2.42 | 3.51 | 0.000 | 3.19 | 3.59 | 0.000 |
| Apt-Apt | | 0.87 | 2.33 | 0.023 | 1.79 | 2.85 | 0.006 |
| Go-Go | | 2.63 | 2.30 | 0.025 | 9.21 | 6.56 | 0.000 |
| Ag-Ag | | 2.42 | 2.57 | 0.013 | 6.58 | 5.57 | 0.000 |
| Cdl-Cdl | | 4.28 | 4.64 | 0.000 | 7.73 | 6.55 | 0.000 |
| Zy-Go | dx | 2.28 | 2.42 | 0.019 | 6.39 | 5.07 | 0.000 |
| | sin | 2.34 | 2.39 | 0.020 | 7.33 | 6.03 | 0.000 |
| Sor-Or | dx | 1.38 | 2.99 | 0.004 | 2.42 | 4.96 | 0.000 |
| | sin | 1.62 | 3.78 | 0.000 | 2.43 | 5.20 | 0.000 |

t = results of t-tests of the differences between males and females
NS = not significant intersexual difference





TABLE 6. Intersexual differences (d) in parameters of shape and position at the age of 5 years and in adults.

| Variable | 5 years | | | Adults | | |
|---|---|---|---|---|---|---|
| | d | t | p | d | t | p |
| **Neurocranium** | | | | | | |
| S-N-F | 0.66 | 0.63 | 0.529 | –1.95 | 2.46 | 0.017* |
| N-S-Br | –0.54 | 0.64 | 0.522 | 1.35 | 1.43 | 0.157 |
| N-S-L | –0.78 | 0.64 | 0.523 | –1.97 | 1.64 | 0.105 |
| Ba-O/NSL | –3.06 | 2.36 | 0.022* | –5.29 | 3.97 | 0.000* |
| **Cranial base** | | | | | | |
| N-S-Ba | –0.01 | 0.01 | 0.993 | 1.59 | 1.20 | 0.255 |
| N-S-Cd | 0.73 | 0.34 | 0.787 | 1.14 | 0.64 | 0.571 |
| **Face** | | | | | | |
| N-S-Go | 0.40 | 0.41 | 0.735 | 0.56 | 0.59 | 0.600 |
| N-S-Pgn | 0.93 | 1.02 | 0.339 | 1.89 | 1.81 | 0.079 |
| S-N-Rhi | –4.06 | 2.90 | 0.005* | 0.09 | 0.06 | 0.981 |
| S-N-Ss | –2.12 | 2.35 | 0.023* | –0.20 | 0.21 | 0.880 |
| S-N-Pr | –1.93 | 2.03 | 0.050* | –1.15 | 1.21 | 0.250 |
| S-N-Id | –1.75 | 1.89 | 0.069 | –0.55 | 0.61 | 0.590 |
| S-N-Sm | –1.77 | 2.04 | 0.049* | –0.41 | 0.45 | 0.706 |
| S-N-Pg | –1.50 | 1.70 | 0.100 | –0.37 | 0.39 | 0.747 |
| Ss-N-Sm | –0.34 | 0.63 | 0.532 | 0.21 | 0.54 | 0.588 |
| Pr-N-Id | –0.19 | 0.55 | 0.636 | –0.60 | 1.63 | 0.108 |
| N-Ss-Pg | 1.09 | 0.98 | 0.360 | 0.62 | 0.49 | 0.624 |
| PL/NSL | 0.20 | 0.29 | 0.825 | 1.60 | 1.92 | 0.062 |
| OL/NSL | 0.51 | 0.58 | 0.615 | 0.54 | 0.50 | 0.670 |
| ML/NSL | –0.62 | 0.51 | 0.665 | 0.88 | 0.54 | 0.641 |
| ML/RL | –0.12 | 0.08 | 0.972 | 0.72 | 0.44 | 0.715 |
| CL/ML | 1.43 | 1.17 | 0.267 | –0.20 | 0.14 | 0.935 |
| RL/NSL | –0.50 | 0.42 | 0.730 | 0.16 | 0.15 | 0.923 |
| PL/ML | –0.83 | 0.69 | 0.536 | –0.61 | 0.38 | 0.754 |
| ASL/PL | –1.99 | 0.98 | 0.363 | –4.00 | 2.40 | 0.020* |
| +1/PL | –1.20 | 0.64 | 0.571 | –0.88 | 0.58 | 0.268 |
| –1/ML | 2.70 | 1.73 | 0.096 | 0.34 | 0.19 | 0.899 |
| +1/–1 | –2.76 | 1.29 | 0.218 | 1.15 | 0.58 | 0.658 |
| Cd-NSL | 0.34 | 0.60 | 0.550 | 0.53 | 0.65 | 0.518 |
| Ptm-VL | –0.09 | 0.19 | 0.848 | –1.09 | 1.91 | 0.060 |
| Pmp-VL | –0.48 | 0.86 | 0.396 | –1.07 | 1.40 | 0.165 |
| Is-Ii | –0.25 | 0.69 | 0.492 | –0.98 | 3.49 | 0.000* |
| **Soft profile** | | | | | | |
| S-N'-Ss' | –1.71 | 1.85 | 0.074 | –0.03 | 0.03 | 0.997 |
| S-N'-Sm' | –1.34 | 1.63 | 0.118 | –0.43 | 0.47 | 0.637 |
| S-N'-Pg' | –1.30 | 1.65 | 0.113 | –0.62 | 0.68 | 0.541 |
| N'-Prn-Pg' | 1.03 | 0.86 | 0.427 | 0.16 | 0.14 | 0.931 |
| N'-Sn-Pg' | 0.35 | 0.28 | 0.832 | –0.48 | 0.32 | 0.801 |
| Ss'-N'-Sm' | –0.36 | 0.71 | 0.521 | 0.57 | 1.30 | 0.214 |
| Ls+Li | –0.21 | 0.50 | 0.621 | 0.42 | 1.00 | 0.321 |
| **Proportions** | | | | | | |
| S-Go%N-Gn | 0.79 | 0.92 | 0.393 | 0.30 | 0.26 | 0.849 |
| N-Sp%N-Gn | 0.43 | 0.80 | 0.463 | –0.52 | 0.87 | 0.422 |

minus symbol = larger value in females
t = results of t-tests of the differences between males and females
* significant intersexual difference

TABLE 7. Intersexual differences of the size in females expressed in percent of the size in males.

| Variable | | girls % boys | females % males |
|---|---|---|---|
| **Neurocranium** | | | |
| N-Op | | 96.96> | 96.59 |
| Ba-Br | | 95.74> | 95.53 |
| Ba-L | | 98.01> | 96.91 |
| S-P | | 96.96 | <97.06 |
| **Cranial base** | | | |
| N-S | | 95.41 | <96.44 |
| S-Ba | | 94.41> | 92.49 |
| **Face** | | | |
| N-Rhi | | 96.92 | <97.77 |
| N-Sp | | 94.87> | 92.75 |
| N-Pr | | 95.96> | 93.15 |
| N-Gn | | 95.74> | 91.74 |
| Sp-Is | | 97.23> | 95.19 |
| Pr-Id | | 89.17 | <92.90 |
| Ii-Gn | | 97.11> | 90.55 |
| Id-Gn | | 99.36> | 89.21 |
| Sp-Pg | | 96.14> | 91.07 |
| S-Go | | 94.52> | 91.14 |
| Cd-Go | | 93.69> | 89.61 |
| Pgn-Go | | 98.98> | 95.17 |
| Ss-Pmp | | 97.32> | 91.55 |
| Pmp-Ba | | 97.00 | <97.30 |
| Pmp-NSL | | 95.42 | <95.63 |
| Pr-PL | | 97.74> | 97.45 |
| **Soft Profile** | | | |
| N'-Prn | | 95.84> | 93.37 |
| N'-Sn | | 95.62> | 93.71 |
| N'-Sto | | 94.80> | 92.42 |
| N'-Pg' | | 97.52> | 92.71 |
| Prn-Sn | | 98.37> | 97.46 |
| Prn-Sp | | 94.13> | 87.92 |
| Sn-Sto | | 92.82> | 88.70 |
| **A-P Projection** | | | |
| Eu-Eu | | 96.66> | 95.34 |
| Lf-Lf | | 94.24 | <96.56 |
| Lo-Lo | | 94.64 | <95.93 |
| Ms-Ms | | 96.16> | 93.75 |
| Zy-Zy | | 95.04> | 93.90 |
| Mo-Mo | | 94.36 | <98.99 |
| Ek-Ek | | 95.08> | 94.51 |
| Mo-Ek | dx | 95.58> | 93.19 |
| | sin | 95.86> | 93.10 |
| Em-Em | | 95.68> | 94.96 |
| Apt-Apt | | 96.47> | 94.42 |
| Go-Go | | 96.69> | 91.08 |
| Ag-Ag | | 96.69> | 92.75 |
| Cdl-Cdl | | 95.60> | 93.40 |
| Zy-Go | dx | 95.00> | 89.80 |
| | sin | 94.82> | 82.22 |
| Sor-Or | dx | 96.22> | 93.97 |
| | sin | 95.57> | 93.96 |

> = smaller intersexual difference in childhood
< = smaller intersexual differences in adults

The intensive growth of the mandibular branch is apparent from the distance Zy-Go (37% and 29%). Craniograms of the AP projection (*Figures 4–5*) also indicate the lateroinferior shift of orbits in relation to HL.

Parameters of the soft profile confirm the intensive vertical growth of the face, in particular the length of the nose (N'-Prn, 40% and 37%). They are consistent with the corresponding parameters of the skeletal profile (N'-Sn, N'-Sto, N'-Pg', 23–33%). The greatest increase occurs however in the depth of the nose (Prn-Sn, 44% and 43%; Prn-Sp, 56% and 46%), while the least growth is recorded in the height of the upper lip (Sn-Sto, 19% and 13%). The percentage of final values of individual characteristics is presented in the same *Tables 1–2* (under % adults).

**Changes in shape:** Statistical characteristics of angular parameters supplemented by maxillary overjet (Is-Ii), prominence of the upper lip (Ls+Li) and some special characteristics (Cd-NSL, Ar-VL, Ptm-VL and Pmp-VL) are presented in *Tables 3–4*. During development the slope of the forehead diminishes, in particular in males (S-N-F, 9° males and 6° females) and the neurocranium (N-S-Br, N-S-L ) undergoes posterior rotation. The changes can be readily followed on craniograms (*Figures 6–7*) which indicate that the posterior cranial fossa increases and descends in relation to the anterior base of the skull. At the same time the inclination of the foramen magnum rotates in a more posterior direction (Ba-O/NSL). The growth of the neurocranial length occurs in the area of the glabella and nasal root and in the occipital area. In adult males the outline of the frontal bone on the craniogram coincides with the outline in 5-year old boys; in females, due to a steeper forehead, there is a certain difference apparent (*Figure 8*).

The angle of the skull base diminishes slowly during the postnatal period but only in females was the difference between the curvature at the age of 5 years and in adult age significant (N-S-Ba). In the flexion of lateral areas of the base no difference was recorded (N-S-Cd). There is a marked increase in the proclination of the nasal bones (S-N-Rhi by 15° and 11°) but the protrusion of the upper jaw (S-N-Ss) changes little (only in males by 2°). This is the result of the same amount of growth of the anterior base and depth of the maxilla. Marked proclination of the upper alveolar process (ASL/PL, 19° and 21°) causes an increase in its protrusion (S-N-Pr). As the mandibular body grows more than the length of the anterior base, the protrusion of the lower jaw increases (S-N-Id, S-N-Sm, S-N-Pg). Therefore sagittal jaw relations (Ss-N-Sm) diminish similarly to the convexity of the face (N-Ss-Pg). Maxillary overjet of the incisors prevents excessive protrusion of the mandible which recedes slightly (N-S-Go) with a steeper position of its branch (RL/NSL) and at the same time occurs an adaptive reduction of the angle of the chin (CL/ML). This does not cause any changes in the intraalveolar relations (Pr-N-Id). Because the ramus of the mandible is the most intensively growing structure of the splanchnocranium, the steepness of the mandibular body





decreases (ML/NSL) as well as the inclination of the occlusal plane (OL/NSL), vertical jaw relations (PL/ML) and the gonial angle (ML/RL). The direction of mandibular growth as a whole is however constant (N-S-Pg). The slope of the palatal plane does not change (PL/NSL), the palate descends to a lower level and the anteroposterior position of the maxilla in relation to the skull base remains the same (Ptm-VL, Pmp-VL). In relation to the base the temporomandibular joint is displaced in a posterior and inferior direction (Cd-NSL, Ar-VL). As compared to the deciduous the permanent upper and lower incisors are more proclined (+l/PL, -l/ML) and the interincisal angle is thus markedly reduced (+1/–1). The maxillary overjet (Is-Ii) is greater in the larger permanent incisors.

Angles of the soft profile confirm the increase in protrusion of the lower face (S-N'-Sm', S-N'-Pg') but also of the upper face (S-N'-Ss'). The convexity of the soft profile is therefore the same at the age of 5 years and in adult age (N'-Sn-Pg'), similarly to the sagittal relation of the upper and lower face (Ss'-N'- Sm'). Since the depth of the nose and its prominence increases most up to adult age, the total convexity of the face including the nose (N'-Prn -Pg') increases as well. The prominence of the upper lip in relation to the lower lip does not change between childhood and adult age (Ls+Li).

**Intersexual differences:** Significant intersexual differences in adult age (*Table 5*) were recorded virtually in all dimensions with the exception of the interocular distance (Mo-Mo), the length of the nasal bones (N-Rhi), the height of the upper alveolar process (Pr-PL) and dentoalveolar component (Sp-Is), the depth of the bony nasopharynx (Pmp-Ba) and the depth of the nose (Prn-Sn). In children there are more insignificant differences (*Table 5*): in addition to those mentioned they include the length and height of the mandibular body (Pgn-Go, Id-Gn), the height of the lower face (Sp-Pg), the height Ba-L and on the soft profile also the height of the whole face (N'-Pg'). However the differences in the interocular distance (Mo-Mo) and the depth of bony nasopharynx (Pmp-Ba) are significant. Regardless whether intersexual differences are or are not significant, in the face they are with a few exceptions (N-S, N-Rhi, Pmp-NSL, Pmp-Ba, Mo-Mo) always smaller in childhood (*Table 7*). On the neurocranium the differences are irregular and small.

Intersexual differences also occur in the amount of relative growth – with several exceptions (S-P, N-S, N-Rhi, Pmp-Ba), where the differences are small (0.4–1.2%) the relative "increments" in boys are greater (*Table 1 vs. 2*). Boys attain at the age of 5 years a lower percentage of the final value of the basic characteristics. However the differences in dimensions of the neurocranium and the cranial base as well as in parameters of the width of the face (except the lower jaw) are slight as well.

Intersexual differences in the configuration of the cranium and its different structures are in both childhood and adult age much smaller than the differences in the size (*Table 6*). In adult age among the investigated characteristics a significant difference was recorded only in the steeper inclination of the forehead (S-F-N), the more anterior inclination of the foramen magnum (Ba-O/NSL), the greater proclination of the upper alveolar process (ASL/PL) and greater overjet (Is-Ii) in females. No differences were found in the other characteristics, inclusive of the prominence of the upper lip. In children there was a significant difference only in the more anterior inclination of the foramen magnum (Ba-O/NSL) and the greater proclination of the nasal bones (S-N-Rhi) and protrusion of the upper jaw (S-N-Ss, S-N-Pr) in girls. In the protrusion of the mandible (S-N-Id, S-N-Sm, S-N-Pg) there is a similar difference but it is not significant ($p < 0.1$).

## DISCUSSION

The findings indicate a difference in the shaping of the cranium at the age of 5 years and in adult age. An advantage of X-ray cephalometric studies is that they allow to evaluate, with fair accuracy, changes in shape of inner components of the skull, and follow up mutual relations between craniofacial structures, in particular during development. A disadvantage is the laborious assembling of large groups from healthy populations. Such data are therefore very valuable. They also substitute for the shortage of craniological studies based necessarily on inaccurately defined and non-representative groups of post-mortem skulls.

During the period investigated the characteristics of the neurocranium grow least, attaining more than 90% of the final size at the age of 5 years, and the height of the vault reaches almost its final size (*Tables 1–2*). It belongs to the neural growth type (Baughan *et al.* 1979). A transition to the facial type of growth is displayed by the length (N-S) and width (Lo-Lo) of the anterior skull base with 88 or more percent of the final size reached by the age of 5 years, while the length of the posterior base (S-Ba) grows similarly as the facial parameters. The difference is due to the ossification of the synchondroses of the anterior base up to the age of 6 years; subsequently the growth occurs only by apposition in the area of the nasal root and glabella. On the contrary synchondrosis of the posterior cranial base is active up to the age of 18 years. Parameters of the orbits (Mo-Ek, Mo-Mo, Ek-Ek; *Tables 1, 2*) are also close to the neural type of growth. As to facial characteristics the least amount of growth was recorded in the depth of the maxilla (Ss-Pmp) and depth of the bony nasopharynx (Pmp-Ba), the latter increases only by growth of the posterior base and the descent of the palate. The growth of the width of the dentoalveolar arch (Em-Em) is also slight. The other facial parameters grow by the facial type of growth and reach 75–85% of their final size by the age of 5 years. An exception is only the lower jaw, in particular the ramus which shows the highest growth rate of all facial characteristics (Pgn-Go, Cd-Go, S-Go, Zy-Go, 70–77%). It is a transition to a general skeletal type of growth, typical

for long bones. The increase in width is, however, smaller (Go-Go, Ag-Ag, 76–80%).

Parameters of the soft profile show the same growth rate as skeletal parameters while more intense growth occurs in the length (N'-Prn) and in particular the depth (Prn-Sn, Prn-Sp) of the nose, amounting at the age of 5 years only to 64–73% of its final size. The almost final height of the alveolar process of the maxilla at the age of 5 years (Pr-PL) may be associated with the descent of the permanent incisors before eruption. Conversely, after eruption they alter markedly the anterior dental height (Pr-Id).

The shape and proportion of cranial structures are determined by the amount of growth of individual components. Among facial dimensions, the depth of the maxilla grows the least, and the skeletal profile of the face flattens. Because the height of the mandibular ramus shows the highest growth rate, the mandible rotates in an anterior direction and along with this the steepness of the body and the gonial angle diminish. The other changes in the shape of the lower jaw are a compensational and adaptational response to the amount of growth of different structures while preserving the intermaxillary articulation. The increase of dentoalveolar proclination of the two jaws is the result of resorptive processes at the anterior poles of the jaws (Kurihara *et al.* 1980) which enhance the subspinal and supramental concavities which are only slight in children. In contrast with the slight anterior growth of the maxilla up to adult age the prominence of the nose increases markedly together with the proclination of the nasal bones. The impulses probably originate from the growth of the nasal septum. Because the anterior (N-Sp) and posterior (Pmp-NSL) height of the upper face shows the same growth rate, the slope of the palatal plane does not change during the development. Flattening of the skeletal facial profile (N-Ss-Pg) is masked on the soft profile (N'-Sn-Pg'), probably in conjunction with the protrusive growth of the nose.

Intersexual differences in the size of the face in adult age vary in the majority of characteristics within the range of 5–10%, in the neurocranium in the range of 3–5% (*Table 7*). In children the intersexual differences are as a rule smaller than 5% and this may be partly due to the three-month difference in age, the boys being older. The greater relative growth of cranial parameters in boys than in girls after the age of 5 years results from the greater growth during and after puberty (larger final size) which is however less expressed in the neurocranium. On the contrary virtually no significant intersexual differences were found in the shape of the cranium and its components. In adults intersexual differences consisted only of a steeper slope of the forehead, a greater proclination of the upper alveolar process and of the overjet in women. In childhood girls have a more protruding upper jaw, inclusive of nasal bones, than boys, but there was also a similar difference in the protrusion of the lower jaw, though it was not significant ($p < 0.1$). A more retrognathic facial profile of boys was reported also by Beaton and Cleall (1973).

In the literature, our results can be compared best with the findings of Bishara *et al.* (1984, 1985) who investigated the growth of 8 linear and 10 angular parameters of the cranium in 20 males and 15 females longitudinally from the age of 5 years to adulthood. The authors do not mention relative amounts of growth but the calculated data confirm the most intensive growth of the mandibular branch and the least growth of all investigated facial parameters in the depth of the maxilla. There is also agreement regarding the development of characteristics of shape and position: the angle of protrusion of the upper jaw increased up to adult age only slightly (in females negligibly), the angle of protrusion of the lower jaw increased more markedly and thus the angle of sagittal jaw relations and the convexity of the facial skeletal profile diminished; the steepness of the mandibular body diminished by 7° in males and by 3–5° in females, the direction of growth of the lower jaw (N-S-Pgn) was constant; of the characteristics of proportion there was a relative reduction of the height of the upper face in relation to the face as a whole, and the higher growth rate of the posterior than of the anterior height of the face led to its anteriorotation; the convexity of the soft profile inclusive of the nose increased, while without the nose did not change markedly. The overjet varied throughout the period around 3 mm.

As for European countries, the findings can be compared with the standards of El Batouti *et al.* (1994) for 6–18 year-old Norwegians. The authors investigated on a longitudinal basis 10 linear and 15 angular parameters in 35 males and 39 females at the age of 6, 9, 12, 15 and 18 years. The protrusion of the upper jaw increased only in males, of the lower jaw in both sexes with a simultaneous reduction of the angle of sagittal jaw relations and of the convexity of the face. The slope of the mandibular body diminished and after the eruption of the permanent upper and lower incisors their proclination increased (after the age of 9 years it did not change) and the interincisal angle diminished in size. The slope of the palatal plane did not change nor did the ratio of the height of the upper and lower face. The angle of the skull base was somewhat reduced and the convexity of the soft profile (without the nose) increased only in males. At the age of 6 years an intersexual difference was observed only in the greater inclination of the palatal plane and the relatively greater height of the upper face in boys. In adult age there was, moreover, a greater protrusion of both jaws in males and a larger interincisal angle in females.

Similar findings were recorded in Sweden by Thilander (Friede, Johanson 1974) between the ages of 7 and 13 years. The protrusion of both jaws increased (more markedly the mandible), the sagittal jaw relations, convexity of the face, steepness of the mandibular body and gonial angle diminished, the slope of the palatal plane changed only slightly and the same applies to the inclination of the upper and lower incisors. Also the longitudinal data of Sinclair and Little (1985) at the age of 9, 13 and 20 years indicate a constant growth direction of the lower jaw (N-S-Pgn),





increasing protrusion of both jaws and proclination of the lower incisors, reduction of the steepness of the mandibular body, gonial angle and slightly of sagittal jaw relations, and a slight increase of the angle of the skull base. Lewis and Roche (1977), however, provide evidence of a constant size of the skull base angle after the age of two years with a negligible diminution up to adult age (by 2°).

Apart from atlases which are not readily available (Broadbent *et al.* 1975, Riolo *et al.* 1974, Saksena 1990) some data can be found in the orthodontic literature. However, these usually involve only a limited number of signs, short periods of time (Trenouth *et al.* 1985, 9–11 years) or a certain age group (Björk 1947, Paulin, Thilander 1991 and others). Because of the difficulty to obtain X-ray films in the healthy population, all studies provide important information and gradually construct a picture of the laws governing the craniofacial growth in man and its intra- and interpopulation variability. Undoubtedly, they are also useful with regard to classical craniometric investigations. Further research is therefore essential. It should be aimed at the creation of a comparative atlas of various norms. A similar review of data from the literature on the main angular cranial parameters was published by Schmuth *et al.* (1988).

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Zbyněk Šmahel
Daniel Šabík
Michaela Tomanová
Chair of Anthropology
Faculty of Natural Sciences
Charles University
Viničná 7
128 44 Prague 10
Czech Republic

Živa Müllerová
Dept. for Cleft Defects
Charles University Hospital
Královské Vinohrady
Šrobárova 50
100 34 Prague 10
Czech Republic