ANTHROPOLOGIE • XXXV/1 • pp. 65–76 • 1997

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ROENTGENCEPHALOMETRIC STUDY OF INTRACRANIAL RELATIONS IN EARLY CHILDHOOD

ABSTRACT: Lateral teleroentgenograms of the skull in 27 normal boys and 30 normal girls, ranging in age from 4 to 6 years old, were used to study the correlations between a variety of facial and neurocranial characteristics. The results were compared with similar data obtained in an earlier-reported series of 50 adult males. It was confirmed that the relations between individual cranial components were governed by certain principles, and thus it proved possible to describe compensatory and adaptive mechanisms operating within the skull. The most important characteristic affecting the development of the whole skull represented the curvature of the cranial base, which rotates both the face and the neurocranium and exerts action on numerous further correlations. Also of importance was the length of the mandibular ramus, which acts on the slope of the mandibular body, vertical jaw relations, the shape and position of the lower jaw, and the dentoalveolar inclinations. The lower jaw had a more pronounced effect on the impairment of sagittal jaw relations than the upper jaw, yet the mandible also participated to a larger degree in the compensatory process. The opposite inclination of the upper and lower incisors and the alveolar processes were responsible for compensation. The identical protrusion of both jaws was due to the compensatory mechanisms of both jaws and to the consistent effect of cranial base curvature, rather than to the identical size of the jaws. Vertical growth of the lower face was independent of the vertical growth of the upper face. These findings, as well as some other observations, were consistent with the situation in adults, though there were some slight differences. The adaptive mechanisms and intracranial relations described acted regardless of sex. Comparison with data from the literature disclosed that the same mechanisms operated equally in other ethnic groups of the population, and their main features were also present in other primates.

KEY WORDS: Roentgencephalometry – Intracranial correlations – Compensatory and adaptive mechanisms

INTRODUCTION

The correlation coefficients calculated in adult males were used in our previous study for an analysis of the degree and character of interrelations between a series of craniometric characteristics measured after the termination of growth (Šmahel, Škvařilová 1988). The results revealed varying degrees of interrelation between the size, shape and position of individual craniofacial structures, and showed that these interrelations were governed by certain principles which can be defined. They were determined by growth characteristics (direction and amount of growth) and by compensatory and adaptive mechanisms operating within the skull.

The principles governing relations between individual cranial structures are relatively little known. A thorough knowledge of these principles would require study of the pertinent relations in a variety of age groups. A longitudinal follow-up would be an ideal type of investigation. The present paper sets forth the results of the same kind of

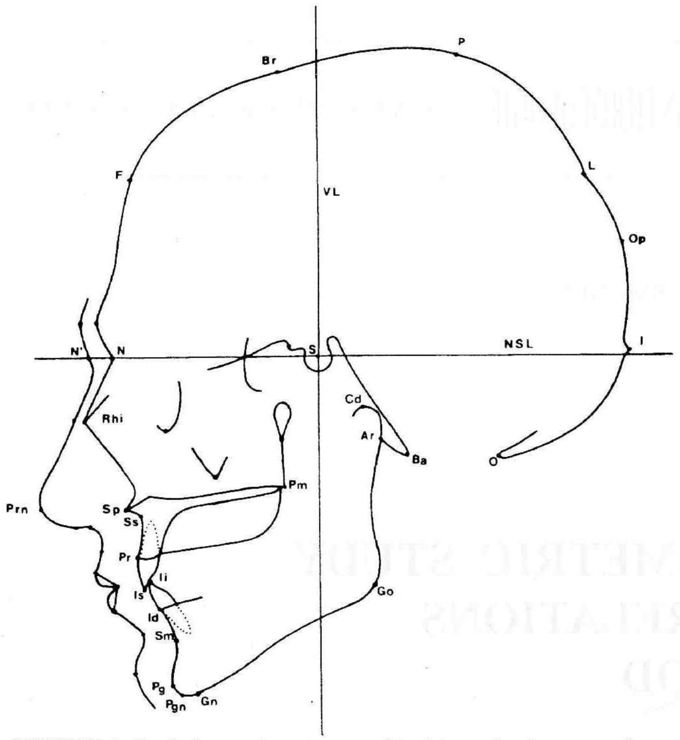

FIGURE 1. Cephalometric points used in this study: Ar – articulare = intersection of the inferior contour of the cranial base and the posterior contour of the ramus; Ba – basion = most posteroinferior point on the clivus; Br – bregma = intersection of the coronal suture and lamina externa of the cranial 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 the ML/RL angle; I – inion = top of the protuberantia occipitalis externa; Id – infradentale = point of the gingival contact with the 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; 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 located by the prolongation of the posterior wall of the spinal canal up to the occipital bone; Op – opisthocranion = point on the surface of the cranial vault farthest from the nasion; P – parietale = intersection of the perpendicular to the dimension Br-L through its midpoint and lamina externa of the cranial vault; Pg – pogonion = most anterior point on the bony chin; Pgn – prognathion = point on the mandibular symphysis farthest from Cd; Pm – pterygomaxillare = intersection of palate line PL with the pterygomaxillary fissure; Pr – prosthion = point of gingival contact with the upper central incisor; Prn – pronasale = point on the top of the apex nasi; Rhi – rhinion = most inferior point on the nasal bones; S – sella = center of sella turcica; Sm – supramentale = deepest point on the anterior contour of the mandibular symphysis; Sp – spinale = tip of the anterior nasal spine; Ss – subspinale = deepest point of the subspinal concavity.

analysis as in the above-mentioned study, this time using subjects in early childhood. The aim of the present investigation was to determine to what extent the character and degree of intracranial relations in children was in agreement with the relevant data in adults, and to describe the interrelations determined. Attention was also given to intersexual differences.

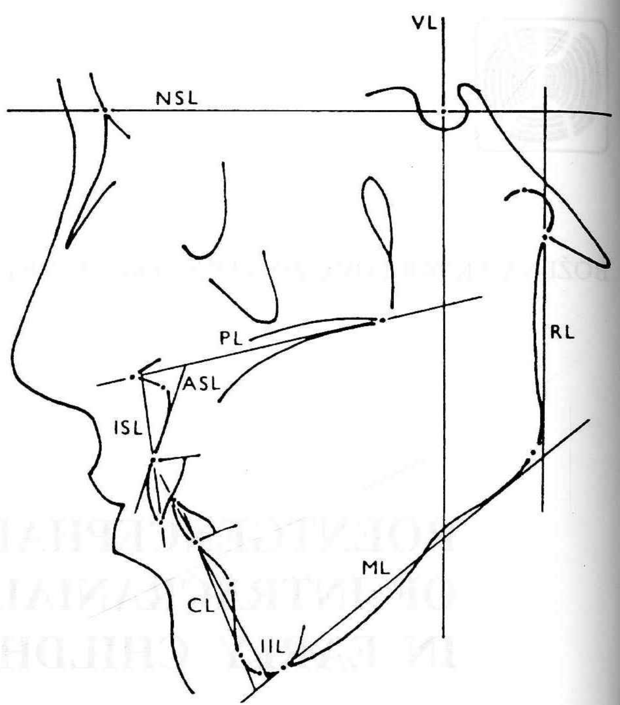

FIGURE 2. Reference lines: NSL = line through N and S, VL = perpendicular to NSL through S, PL = line through the anterior and posterior nasal spine, ML = tangent to the mandibular body through Gn, RL = tangent to the mandibular ramus through Ar, CL = line through Pg and Id, ASL = tangent to the upper alveolar process through Pr, ISL = line through Is and Pr, IIL = line through Ii and Id.

MATERIAL AND METHODS

27 normal boys and 30 normal girls, ranging in age from 4 to 6 years old, were assigned to the series. The mean age was 5 years and 2 months for boys and 4 years and 11 months for girls. All the subjects were Czechs (Middle European Caucasians), and were selected at random from Prague kindergartens. Only individuals who had not been subjected to orthodontic therapy and had a clinically acceptable occlusion without obvious facial disharmony were examined. All individuals still had deciduous incisors.

The X-ray films were made under standard conditions (focus-object distance 370 cm, object-film distance 30 cm, magnification 8.1%), with centric occlusion and with the head fixed by a cephalostat. The craniometric points and reference lines used for the interpretation of X-ray films are presented in *Figures 1 and 2*. In the case of double contours due to differences between the right and left sides, the relevant points were marked at the midpoint between both contours. All measurements were carried out by one of the authors. With one exception (N-Prn), characteristics of the soft profile were not included in our study.

Our previous study (Šmahel, Škvařilová 1988) also included an assessment of measurement error for the investigated characteristics. The variance of error, determined on the basis of two measurements, was in most cases below 5 percent of the total variance for the relevant parameter. This confirmed the high degree of reliability of the measurements. A larger measurement error (5–10%)

TABLE 1. Correlation coefficients of neurocranial variables in early childhood (upper right section of the table) and in adulthood (lower left section of the table).

	N-S-Ba	S-Ba-O	S-N-F	N-S-Br	N-S-L	Op-NSL[1]	O-NSL	S-P	Ba-Br	S-N-Rhi	S-N-Ss
N-S-Ba	–	.403**	.569***	.515***	–.425**	.447***	–.827***	.354**	.132	–.562***	–.588***
S-Ba-O	.504***	–	.051	.015	–.040	–.115	.043	.027	–.199	–.043	.049
S-N-F	.422**	.010	–	–.504***	–.289*	.603***	–.618***	.498***	.271*	–.316*	–.421**
N-S-Br	–.330*	.206	–.654***	–	.399**	–.395**	.646***	–.047	–.002	.360**	.485***
N-S-L	–.672***	–.011	–.536***	.729***	–	–.348**	.469***	–.062	.020	.124	.315*
N-S-I	–.681***	.068	–.385**	.515***	.776***	–	–.518***	.542***	.238	–.322*	–.356**
O-NSL	–.829***	–.054	–.545***	.595***	.753***	.783***	–	–.159	.033	.463***	.597***
S-P	.367**	.053	.427**	–.185	–.245	–.233	–.315*	–	.808***	–.332*	–.317*
Ba-Br	–.278*	–.472***	.254	–.081	–.041	.075	.218	.500***	–	–.343**	–.352**
S-N-Rhi	–.480***	.000	–.302*	.315*	.379	.453***	.522***	.024	.145	–	.655***
S-N-Ss	–.473***	–.016	–.200	.272	.446***	.417**	.534***	.093	.258	.677***	–

* correlation coefficient significant at $p<0.05$, ** $p<0.01$, *** $p<0.001$
-- significant difference between correlation coefficients in early childhood and adulthood at $p<0.05$, — at $p<0.01$ (underlined)
[1] direct measurement Op-NSL yields an opposite symbol than when the characteristic is expressed in terms of an angle N-S-I

was ascertained only in characteristics that included the condylion point (Cd), and also in the inclination of the upper alveolar process (ASL/PL) and angle S-Ba-O. A similarly slight reduction in measurement precision was recorded in the present study for angle N-S-L. Therefore, the correlation coefficients for these characteristics might be slightly underestimated. Because of the missing development of the external occipital protuberance in children, it was decided to measure the dimension Op-NSL, instead of the angle N-S-I as determined in adults. However, the less precise localization of the Op-point resulted in higher measurement error for this characteristic (13.7%), and thus the values obtained can only serve for rough orientation.

All the characteristics selected for our analysis are presented in the form of tables. Correlation coefficients for the neurocranium (*Table 1* plus S-N-Rhi) and for the bony facial framework (*Table 2*) were calculated for all combinations of characteristics separately. In another table are presented the characteristics of the soft profile *(Table 3)*. Additional correlation coefficients are mentioned in the text. The perpendicular distance of a point from the reference line is marked as O-NSL, and an angle as N-S-Ba or as a fraction of the two reference lines forming the given angle (RL/NSL).

Correlation coefficients were calculated for boys and girls separately and for a pool of both sexes. The values of coefficients were tested with the t-test, and compared to one another with the t-test after z-transformation (intersexual differences and differences from the coefficients in adults). In the text all coefficients exceeding 0.7 are designated as high, and values ranging from 0.5 to 0.7 as moderately high. Lower values of correlation coefficients which were still significant are designated as low (while insignificant coefficients referred to independent characteristics). However, the results were described with regard to the dynamics of the interrelations or the underlying causes. Therefore, for purposes of better understanding, certain relations were illustrated by craniograms representing both marginal situations and an average pattern, determined on the basis of the numerical values of a given characteristic (e.g. the angle of the cranial base N-S-Ba, *Figure 3*). About 10–12 individuals with the highest or lowest value for a given characteristic were assigned to marginal categories, while other individuals had an average pattern. This classification was in agreement with that based on the use of marginal value $\overline{X} \pm 1$ SD. For calculations and the construction of craniograms, larger numbers of parameters than for the correlation analysis were used. These procedures were applied only to the pooled sexes.

RESULTS

The correlation coefficients calculated for both sexes were in good agreement. Out of the 55 coefficients for neurocranial parameters (*Table 1*), two coefficients showed a significant intersexual difference at the $p < 0.05$ level (i.e. 3.54%) and one at the $p < 0.01$ level (1.82%). These consisted exclusively of characteristics with a low precision of measurement (Op-NSL and N-S-L). In the case of facial characteristics (*Table 2*), of the 325 coefficients a similar intersexual difference was recorded in 13 (4.0%) at the $p < 0.05$ level and in 3 (0.9%) at the $p < 0.01$ level. The latter included coefficients of characteristics exposed to the effect of extrinsic factors (dentoalveolar inclinations IIL/NSL and ASL/PL). The coefficients presented in *Table 3* did not differ in boys and in girls. The recorded intersexual differences were in good agreement with the anticipated frequency of accidentally significant results recorded during the use of large numbers of tests, provided that the investigated parameters were independent. Despite the fact that craniometric characteristics were more or less interrelated, the frequency of anticipated significant differences did not increase, and their occurence in the correlation tables was accidental. This confirmed the absence of any differences between intracranial correlations between the two sexes. Therefore, the results presented in the subsequent text were obtained after pooling both sexes. For purposes of comparison, the tables also contain correlation coefficients calculated for a series of adult males (left lower segment of the tables).

TABLE 2. Correlation coefficients of facial variables in early childhood (upper right section of the table) and in adulthood (lower left section of the table).

	Ss-Pm	N-S	ML/RL	S-N-Pg	Pgn-Go	Cd-Go	RL/NSL	N-S-Ba	N-S-Cd	N-S-Pm	CL/ML	Id-Gn	S-N-Ss
[1]Ss-N-Pg	.021	–.457***	.207	–.227	–.410**	–.347**	.198	–.104	–.144	.016	.266*	.325*	.379**
Ss-Pm	–	.537***	–.053	.136	.339*	.469***	–.120	.156	–.116	.016	.276*	.289*	.141
N-S	.273	–	–.098	–.148	.351**	.553***	–.095	.146	–.020	–.163	.247	.019	–.412**
ML/RL	–.296*	–.038	–	–.272*	–.478***	–.445***	–.558***	.249	.082	.098	–.183	.200	–.136
S-N-Pg	.272	–.075	–.256	–	.417**	.199	–.288*	–.548***	–.566***	–.560***	–.113	.058	.815***
Pgn-Go	.319*	.217	–.364**	.410**	–	.492***	.375**	–.133	–.124	.027	–.112	.228	.153
Cd-Go	.421**	.342*	–.402**	.380**	.473***	–	.116	–.053	–.062	.022	.169	.136	–.017
RL-NSL	–.116	–.135	–.383**	–.608***	.148	–.015	–	.035	.052	.377**	.006	.065	–.156
N-S-Ba	.072	.023	–.116	–.486***	–.117	–.255	.305*	–	.616***	.542***	.025	–.021	–.583***
N-S-Cd	–.011	.270	.021	–.564***	.098	.057	.345*	.573***	–	.588***	.048	–.088	–.624***
N-S-Pm	.203	–.380**	–.051	–.406**	–.002	–.101	.486***	.382**	.297*	–	–.292*	.071	–.522***
CL/ML	.270	–.089	–.469***	.000	–.152	.163	.134	.112	–.109	–.096	–	.049	.051
Id-Gn	.073	–.030	.348*	–.147	.177	.242	.151	–.348*	–.084	.056	.083	–	.248
S-N-Ss	.472***	–.242	–.119	.780***	.246	.307*	–.496***	–.474***	–.555***	–.332*	.265	.183	–
ML/NSL	–.375**	–.130	.754***	–.690***	–.258	–.418**	.311*	.100	.282	.293*	–.375**	.476***	–.454***
ASL/PL	.093	.069	–.114	.391**	.189	.202	–.295*	.045	.007	–.284*	.277	–.171	.210
ISL/PL	–.001	.041	–.010	.309*	.200	–.009	–.250	.015	–.065	–.187	.114	–.134	.096
IIL/NSL	.061	.078	–.347*	.479***	.504***	.250	–.017	–.240	–.145	–.130	–.259	–.180	.182
N-Sp	.262	.173	.033	–.251	.452***	.313*	.306*	.200	.509***	.393**	–.139	.321*	–.145
N-Gn	.012	.054	.423**	–.268	.289*	.238	.286*	–.231	.069	.248	–.234	.810***	–.064
S-Go	.453***	.071	–.360**	.539***	.422**	.743***	–.139	–.429**	–.386**	–.057	.279*	.396**	.567***
Pm-NSL	.202	.000	.149	.414**	.470***	.426**	–.200	–.574***	–.274	.120	–.258	.491***	.425**
Pr-PL	–.172	–.078	.342*	–.239	–.014	–.001	.223	–.226	–.152	.061	–.063	.572***	–.039
Sp-Pg	–.182	–.121	.550***	–.272	–.105	–041	.157	–.278*	–.242	.036	–.083	.742***	.001
S-Ba	.246	.010	.044	.349*	.256	.254	–.345*	–.338	–.074	.068	–.178	.245	.301*
Cd-NSL	.134	–.247	.004	.485***	–.036	–.095	–.402**	–.465***	–.796***	–.155	.208	.211	.556***

	ML/NSL	ASL/PL	ISL/PL	IIL/NSL	N-Sp	N-Gn	S-Go	Pm-NSL	Pr-PL	Sp-Pg	S-Ba	Cd-NSL
[1]Ss-N-Pg	.402**	–.257	–.243	–.503***	–.177	.066	–.180	–.142	.230	.333*	–.209	.128
Ss-Pm	–.189	.012	–.005	–.204	.275*	.333*	.498***	.364***	.135	.208	.316*	.355**
N-S	–.190	.050	.087	–.122	.473***	.377**	.478***	.356**	.030	.106	.383**	.141
ML/RL	.658***	–.007	.018	–.350**	–.167	.069	–.411**	–.249	.193	.282*	–.049	–.006
S-N-Pg	–.601***	.526***	.306*	.489***	–.337*	–.317*	.239	.132	–.210	–.256	.057	.376**
Pgn-Go	–.233	.186	.253	.343**	.453***	.477***	.545***	.692***	.214	.218	.417**	.260
Cd-Go	–.407**	.066	–.014	.101	.477***	.467***	.876***	.627***	.149	.184	.569***	.224
RL-NSL	.250	–.296	–.085	–.097	.490***	.465***	.154	.338*	.228	.261	–.007	–.156
N-S-Ba	.316*	–.238	–.021	–.249	.218	.164	–.204	–.087	.050	.026	–.087	–.404**
N-S-Cd	.165	–.276*	–.078	.020	.099	.005	–.278*	–.097	.006	–.096	.074	–.616***
N-S-Pm	.467***	–.501***	–.358**	–.140	.425**	.450***	.015	.322*	.324*	.273*	.251	–.202
CL/ML	–.217	.209	.152	–.370**	–.055	–.044	.130	–.128	–.099	.058	–.088	–.044
Id-Gn	.283*	–.089	–.043	–.046	.147	.477***	.309*	.330*	.442**	.539***	.258	.413**
S-N-Ss	–.332*	.347**	.171	.194	–.425**	–.261	.120	.041	–.063	–.045	–.070	.434***
ML/NSL	–	–.313*	–.082	–.493***	.242	.502***	–.344**	.003	.446***	.569***	–.048	–.173
ASL/PL	–.328*	–	.742***	.113	–.140	–.229	.029	–.153	–.446***	–.225	–.185	.101
ISL/PL	–.190	.772***	–	–.086	–.190	–.096	–.116	–.125	–.328*	–.070	–.290*	–.136
IIL/NSL	–.363**	–.045	–.082	–	–.050	–.286*	.087	.085	–.193	–.348**	.133	.073
N-Sp	.276	.147	.173	–.050	–	.758***	.514***	.643***	.197	.244	.444***	.105
N-Gn	.645***	–.185	–.124	–.161	.551***	–	.588***	.699***	.656***	.783***	.524***	.303*
S-Go	–.465***	.132	.008	.123	.156	.320*	–	.685***	.324*	.374**	.581***	.622***
Pm-NSL	.036	–.111	–.033	.221	.334*	.561***	.598***	–	.376**	.372**	.707***	.347**
Pr-PL	.499***	–.423**	–.510***	–.097	–.148	.603***	.160	.265	–	.797***	.282*	.326*
Sp-Pg	.669***	–.324*	–.295*	–.261	–.036	.761***	.140	.299*	.845***	–	.302*	.378**
S-Ba	–.199	.017	–.012	.065	.158	.183	.494***	.497***	–.069	–.059	–	.292*
Cd-NSL	–.284*	.007	.068	–.060	–.343*	.047	.541***	.347*	.174	.229	.425**	–

* correlation coefficient significant at p<0.05, ** p<0.01, *** p<0.001

-- significant difference between correlation coefficients in early childhood and adulthood at p<0.05, — at p<0.01 (underlined)

[1] angle Ss-N-Pg was not calculated in the previous series of adults

Neurocranium

Correlation coefficients (*Table 1*) confirmed the importance of the curvature of the cranial base (N-S-Ba) for the configuration of the neurocranium. Increasing flexion of the base resulted in posterior rotation of the neurocranium (N-S-Br, N-S-L, Op-NSL), and led to less steep sloping of the frontal bone (S-N-F) and displacement of the posterior cranial fossa anteriorly (N-S-Ba) and inferiorly (O-NSL). There was a simultaneous reduction of the height of the cranial vault (S-P), while the height of the neurocranium (Ba-Br) remained unchanged, as illustrated in *Figure 3*. A more pronounced curvature of the base was accompanied by a forward inclination of the foramen magnum (Fig. 3, N-S-Ba vs. Ba-O/NSL, r = 0.467, p < 0.001). The angle which the foramen magnum formed with the plane of the clivus (S-Ba-O) increased or decreased parallel to changes of the angle of the cranial base. This resulted from an indispensable adaptive process. Other significant correlations were related to the rotation of the cranial vault (between S-N-F, N-S-Br, N-S-L, Op-NSL and O-NSL, resp.). The frontal slope (S-N-F) was correlated to the height of the cranial vault (S-P) and also, slightly, to the height of the neurocranium (Ba-Br). The height of the cranial vault (S-P) determined the position of the largest occipital vaulting (Op-NSL), and provided an explanation for the 65-percent variability of the neurocranial height (Ba-Br). The length of the anterior cranial base accounted for only 23 percent of neurocranial length variability (N-S vs. N-Op, r = 0.482, p < 0.001). The length of the neurocranium was independent of the curvature of the cranial base (r = 0.154), and was therefore not related to the rotation of the vault. Because of the relation of maxillary protrusion (S-N-Ss) and the proclination of nasal bones (S-N-Rhi) to the curvature of the base (N-S-Ba), they were both equally correlated to the rotation and height of the neurocranium.

Nine (i.e. 16.4%) of the correlation coefficients of the neurocranium investigated differed significantly (at the p < 0.05 level) from the coefficients calculated for the series of adults, and three of them (5.4%) at the p < 0.01 level (*Table 1*). These frequencies were higher than could be anticipated by chance occurrence (5% and 1%). They indicated that, compared to adults, children demonstrated a less close interrelation between parameters which characterize the rotation of the neurocranium (N-S-Br vs. N-S-L, vs. Op-NSL, vs. O-NSL), and, conversely, closer interrelations between the height of the cranial vault and the height of the neurocranium (S-P vs. Ba-Br). The remaining three significant differences included correlations between the height of the cranial vault (S-P) or the neurocranium (Ba-Br) on the one hand, and the protrusion of the upper jaw (S-N-Ss) and the proclination of the nasal bones (S-N-Rhi) on the other. In children these coefficients had a symbol opposite to that in adults, yet their values only ranged up to 0.35. The differences were, therefore, considered accidental.

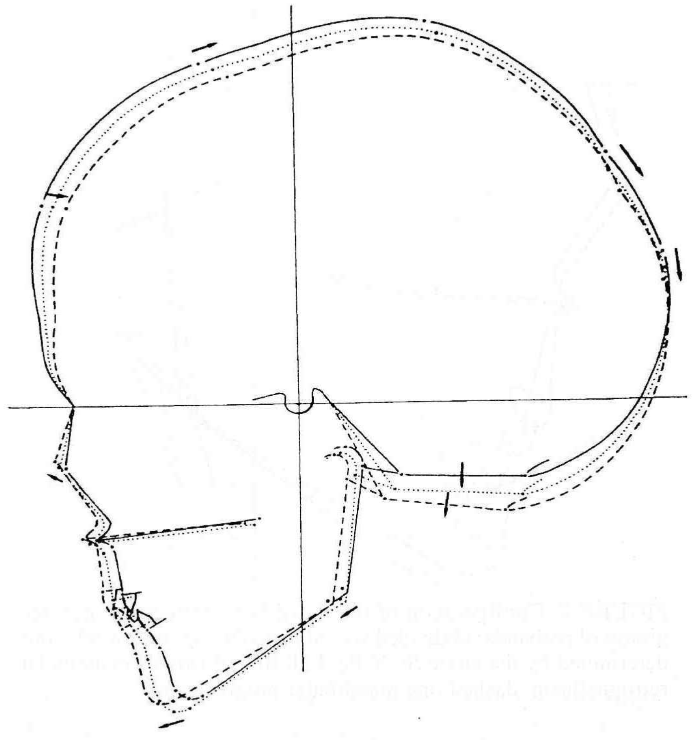

FIGURE. 3. The effect of cranial base flexion on the rotation of the skull.

Cranial base

The curvature of the cranial base (N-S-Ba) exerted a definite action on the rotation of both the neurocranium and the facial skeletal framework (*Table 2, Figure 3*). An acute angle of the cranial base displaced both jaws forwards (S-N-Pg, S-N-Ss and N-S-Pm), led to proclination of the nasal bones (S-N-Rhi, *Table 1*), displaced the temporomandibular joint forwards and downwards (N-S-Cd, Cd-NSL), and resulted in an anterior rotation of the mandible (ML/NSL). In contrast to the situation in adults, we failed to discover a correlation between the posterior height of the whole face and of the upper face (S-Go vs. Pm-NSL). Thus, there were only slight signs of anteinclination of the palatal plane in the presence of an acute angle of the cranial base (*Figure 3*).

The length of the anterior cranial base (N-S) showed only a slight correlation to the length of the posterior part of the base (S-Ba), and a slight or moderately close correlation to the size of certain other facial dimensions (Ss-Pm, Pgn-Go, Cd-Go, N-Sp, N-Gn, S-Go, Pm-NSL). We failed to discover these correlations in adults. The longer the anterior base, the more acute the S-N-Ss angle. The length of the posterior part of the cranial base (S-Ba) was correlated to the size of most facial dimensions, and was closely correlated to the posterior height of the upper face (Pm-NSL). Similar correlations were not recorded in adults, except for associations with posterior facial height (S-Ba vs. Pm-NSL, S-Go, and Cd-NSL).

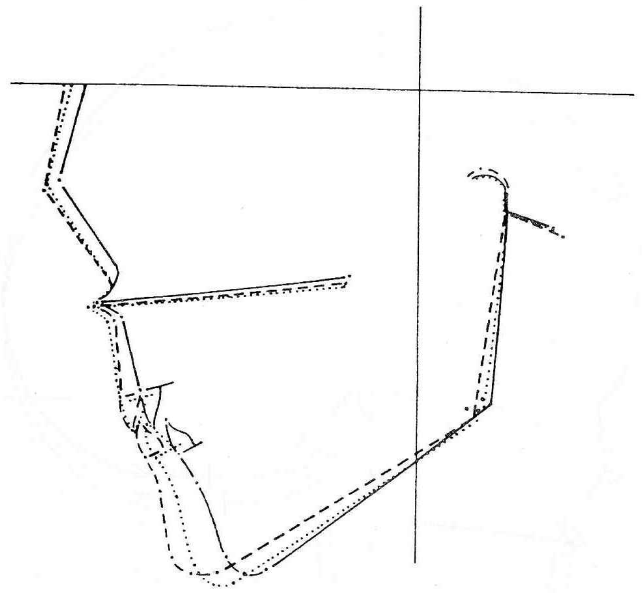

FIGURE 4. Configuration of the facial bony framework in three groups of probands subdivided according to the sagittal jaw relations determined by the angle Ss-N-Pg. Full line illustrates mandibular retrognathism, dashed line mandibular prognathism.

Size of the facial skeletal framework

Correlations between the size of various facial structures were mostly slight as well. The length of the maxilla (Ss-Pm) only showed a moderate correlation to the length of the anterior cranial base (N-S), and a slight correlation to the length of the mandibular body and ramus (Cd-Go, Pgn-Go) and the anterior and posterior height of the upper face (N-Sp, Pm-NSL) and the whole face (N-Gn, S-Go). In adults these interrelations were even slighter, and there was no correlation to the length of the anterior base.

The length of the mandibular ramus (Cd-Go) was essential for the posterior height of the face (S-Go, $r = 0.876$), and showed a moderately close correlation to the posterior height of the upper face (Pm-NSL) and the length of the posterior and anterior cranial base (S-Ba, N-S), as well as a less close correlation to mandibular body length (Pgn-Go) and some other vertical and depth parameters (N-Sp, N-Gn, Ss-Pm). The length of the mandibular body (Pgn-Go) likewise showed similar relationships. The correlations were lower in adults, except for the relation of the length of the mandibular body and ramus ($r = 0.473$). The height of the mandibular body (Id-Gn) showed a closer correlation only to dimensions in which it was integrated (Sp-Pg, N-Gn), as well as to the height of the upper alveolar process (Pr-PL). The latter relation was obviously due to the similar size of the upper and lower teeth. The height of the maxillary alveolar process (Pr-PL) was not correlated to the height of the upper face (N-Sp), though it formed part of the upper jaw. Thus, the vertical growth of the lower face was largely independent. This independence was confirmed by the absence of a correlation between the height of the upper and lower face (N-Sp vs. Sp-Pg). A similar situation was recorded in the series of adult males.

Conceivably close correlations between characteristics were found when one of them formed part of the other (N-Gn vs. N-Sp, Sp-Pg, and Pr-PL). Contrary to the situation in adults, we recorded a very good (moderately close) correlation between the anterior and posterior height of the upper face (N-Sp vs. Pm-NSL) and of the whole face (N-Gn, vs. S-Go). These correlations characterized the similarity in size of related dimensions, and were seen to a greater or lesser extent in the relations between numerous other dimensions.

Position of the jaws

The characteristics of the shape and position of cranial structures were mostly determined by the size of individual skeletal components, and thus represented derived parameters. Protrusion of the maxilla (S-N-Ss) was determined mainly by curvature of the cranial base in the median plane (N-S-Ba) and in the lateral regions (N-S-Cd, Cd-NSL), as well as by the anteroposterior position of the maxilla (N-S-Pm). Rather surprising was the independence of maxillary protrusion from the depth of the maxilla (Ss-Pm). This correlation was also present in adults. There was good correlation to the length of the anterior cranial base (N-S) and the anterior upper face height (N-Sp); when these dimensions were smaller, there was increased protrusion of the upper jaw.

Similarly as in the case of the upper jaw, protrusion of the lower jaw (S-N-Pg) was determined by the curvature of the cranial base (N-S-Ba), the position of the temporomandibular joint (N-S-Cd, Cd-NSL) and the maxilla (N-S-Pm), as well as by inclination of the mandibular ramus (RL/NSL). The protrusion of the lower jaw exerted per se an effect on the inclination of the upper incisors (ISL/PL), the upper alveolar process (ASL/PL) and the lower incisors (IIL/NSL). Given the low correlation between the length of the upper jaw (Ss-Pm) and the length of the mandibular body (Pgn-Go), the close relation between the protrusion of both jaws (S-N-Ss vs. S-N-Pg, $r = 0.815$) was due to the compensatory mechanisms of the lower jaw (inclination of the body and ramus, ML/NSL and RL/NSL) and the action of the cranial base curvature (N-S-Ba, N-S-Cd), rather than to the identical size of both jaws. These observations were in full agreement with the data obtained for adults.

From the above-mentioned observations it follows that the anteroposterior position of the upper jaw (N-S-Pm) was affected by the curvature of the cranial base (N-S-Ba, N-S-Cd), and correlated to the protrusion of the lower jaw (S-N-Pg). Correlation to its own protrusion (N-S-Pm vs. S-N-Ss) amounted only to 0.522, due to the effects exerted by the variability of the length of the anterior cranial base (N-S) and the maxilla (Ss-Pm). An anterior position of the upper jaw was associated with a less steep sloping of the mandibular body (N-S-Pm vs. ML/NSL) and ramus (vs. RL/NSL). It was accompanied by posterior rotation of the cranial vault *(Table 1)*. This relationship was mediated by the angle of the cranial base (*Figure 3*).

Sagittal jaw relations

Subdivision of the individuals according to the size of the Ss-N-Pg angle disclosed that impaired sagittal jaw relations, i.e., a disharmony in the protrusion of both jaws (*Figure 4*), was caused in normal children mainly by the position of the lower jaw. The contribution of the maxilla to this disproportion was much smaller. Correlation coefficients documented that mandibular retrognathism is associated with a shorter mandible (Pgn-Go, Cd-Go) and anterior cranial base (N-S), and with a larger protrusion of the maxilla (S-N-Ss) due to the shorter anterior base (*Figure 4*). There was also a steeper sloping of the mandibular body (ML/NSL). The resulting disproportion was compensated mainly by the proclination of the lower incisors (IIL/NSL) and the alveolar process (Ss-N-Pg vs. CL/NSL, $r = 0.547$, $p < 0.001$), while the inclination backwards of the upper incisors (ISL/PL) and of the alveolar process (ASL/PL) had a much smaller effect (Ss-N-Pg vs. ISL/NSL, $r = 0.199$ and vs. ASL/NSL $r = 0.222$). This compensatory mechanism eliminates the disproportion within the frontal segment of the dentition. The difference in the inclination of the lower incisors and the alveolar process between retrognathic and prognathic mandibular position exceeded by two times the difference recorded in the inclination of the upper incisors and the alveolar process (*Figure 5*). In adult individuals the lower jaw likewise contributed more pronouncedly to compensation than did the upper jaw. Because of these counterdirectional compensatory mechanisms, there were no correlations between the inclination of the upper and lower incisors (ISL/PL vs. IIL/NSL, $r = 0.036$) or of the alveolar processes (ASL/PL vs. CL/NSL, $r = 0.215$).

Inclination of the upper incisors (ISL/PL) and the upper alveolar process (ASL/PL) was related to the protrusion of the lower jaw (S-N-Pg) and the position of the upper jaw (S-N-Pm). The correlation to maxillary protrusion (S-N-Ss) was low, and was impeded by the length of the anterior base (by the position of point N). The inclination of the upper incisors (ISL/PL) was closely related to the inclination of the upper alveolar process (ASL/PL), and the steeper the inclination of these structures, the greater the height of the process (Pr-PL). Inclination of the lower incisors towards the cranial base (IIL/NSL) was affected by the protrusion of the lower jaw (S-N-Pg), not the upper jaw (S-N-Ss), and was correlated to the length (Pgn-Go) and slope (ML/NSL) of the mandibular body, and thus also to the angle of the chin (CL/ML), the gonial angle (ML/RL) and the height of the lower face (Sp-Pg). It was closely related to the inclination of the mandibular symphysis (vs. CL/NSL, $r = 0.708$, $p < 0.001$). The main features recorded in our present study were consistent with the situation in adults, though the interrelations in adults were generally less definite.

Vertical jaw relations and mandibular shape

The length of the mandibular ramus (Cd-Go) had an important effect on these characteristics. Shortening of the ramus (Cd-Go) resulted in a steeper sloping of the body (ML/NSL) and a more obtuse gonial angle (ML/RL). A steep sloping of the body produced impairment of the vertical maxillo-mandibular relations, and led to a hyperdivergence of the planes of both jaw bases. This could result in an open bite. Correlation coefficients and craniograms (*Figure 6*) showed that steep sloping of the body was associated with the retrusion of both jaws (S-N-Pg, S-N-Ss, N-S-Pm), retroinclination of the lower incisors (IIL/NSL), increase of the anterior height of the face (N-Gn, Sp-Pg, Pr-PL) and reduction of the posterior facial height (S-Go). An identical situation was recorded in adults. Inclination of the ramus (RL/NSL) was not correlated to inclination of the mandibular body (ML/NSL), however, the more marked the posterior displacement of the maxilla (N-S-Pm) and the greater its anterior (N-Sp) and posterior height (Pm-NSL), the steeper the slope of the ramus and the more acute the gonial angle (ML/RL). In adults we failed to discover a correlation between the slope of the ramus and the height of the maxilla, while there was a more marked correlation between the protrusion of the lower jaw and the slope of the ramus than was the case in children. Differences between the correlation coefficients were significant. Due to the correlation between the size of the gonial angle (ML/RL) and the length of the mandibular ramus, there was an equally good correlation of this angle to the length of the mandibular body (Pgn-Go) and the posterior facial height (S-Go). On the contrary, there was no correlation between the chin angle (CL/ML) and the parameters investigated, except for inclination of the lower incisors towards the cranial base (IIL/NSL). A flattened gonial angle in adults was associated with a more acute chin angle and with a trend towards increased anterior mandibular height (Id-Gn). The relationship between the gonial angle and the anterior height dimensions of the face (N-Gn, N-Sp) was more marked as well.

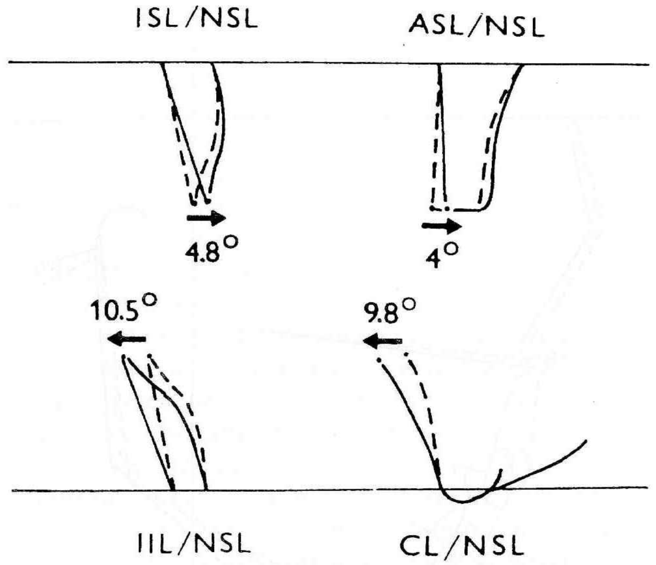

FIGURE 5. Counterdirectional compensatory mechanism in impaired sagittal jaw relations (full line = mandibular retrognathic position, dashed line = mandibular prognathic position).

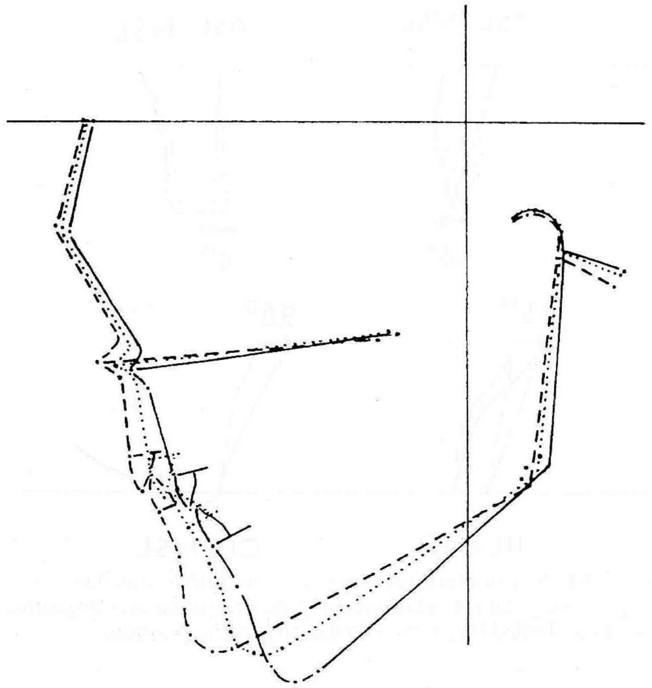

FIGURE 6. Configuration of the facial bony framework in three groups of probands subdivided according to the slope of the mandibular body determined by the angle ML/NSL.

The angle of the temporomandibular joint position (N-S-Cd) showed a good correlation to the angle of the cranial base (N-S-Ba), and thus the correlation coefficients computed for this characteristic were consistent with those of the angle of the base. The vertical position of the temporomandibular joint (Cd-NSL) was likewise related to certain dimensions (Ss-Pm, Id-Gn, N-Gn, S-Go, Pm-NSL, Pr-PL, Sp-Pg, S-Ba).

Nose

The length of the nose (N'-Prn) showed a close correlation (*Table 3*) to the length of the nasal bones (N-Rhi), and increased with the increasing retrusion of the maxilla (S-N-Ss). The length of the nasal bones (N-Rhi) and especially their slope (S-N-Rhi) were equally related to the degree of maxillary retrusion or protrusion; retrusion of the jaw was associated with prolongation and retroinclination of the nasal bones. An identical situation was observed in adults. In children, contrary to adults, no relation was discovered between the length (N-Rhi) and slope (S-N-Rhi) of the nasal bones (*Table 3*).

TABLE 3. Correlation coefficients of nasal variables in early childhood (upper right section of the table) and in adulthood (lower left section of the table).

	N'-Prn	N-Rhi	S-N-Rhi	S-N-Ss
N'-Prn	–	.726***	–.246	–.433***
N-Rhi	.605***	–	–.176	–.343**
S-N-Rhi	–.231	–.420**	–	.656***
S-N-Ss	–.332*	–.299*	.677***	–

* correlation coefficient significant at $p<0.05$, ** $p<0.01$, *** $p<0.001$

no significant difference between correlations coefficients in children and adults

DISCUSSION

The results of analysis of the correlations revealed that the data on the main characteristics were in good agreement with the results of a similar study performed on a series of adult males (Šmahel, Škvařilová 1988). It was confirmed that parameters of the size, shape and position of craniofacial structures are interrelated, and that these relations are governed by certain principles. Small numbers of significant intersexual differences were in agreement with the anticipated frequency rate, and proved the occurrence of identical intracranial relations and compensatory mechanisms in both sexes. Similarly, the number of significant differences between correlations of facial parameters in children and adults did not exceed the anticipated frequency of accidentally significant results in large numbers of tests. Of 300 tests, there were ten significant differences at the $p < 0.05$ level (i.e. 3.3%) and three at the $p < 0.01$ level (1%), amounting to a total of 4.3% (*Table 2*). However, the number of significant differences between the situation in children and in adults exceeded 5% in the case of the neurocranial correlation coefficients. Of the 55 coefficients, six attained a significance level of $p < 0.05$ (i.e 10.9%) and three a level of $p < 0.01$ (5.5%), i.e., 16.4% altogether (*Table 1*). However, these differences were not substantial, and involved rather the degree of interrelation. They could reflect distinct proportions of the neurocranium in children.

Despite the general agreement between the correlations determined for children with those for adults, more detailed analysis disclosed certain differences. Closer correlations between the size of the craniofacial dimensions were recorded in children (note the 51 significant correlations between characteristics of size as compared to 29 in adults, *Table 2*). Thus, the length of the anterior (N-S) and posterior (S-Ba) cranial base showed a correlation to numerous characteristics of the face. In adults there was higher independence between the cranial base and facial parameters, which could be due to the lower growth of the base and early termination of the growth of its anterior length (Doskočil 1961). We failed to ascertain any interrelation between the curvature of the base and the posterior height of the upper face (Pm-NSL) and the whole face (S-Go) in children. The effect of flexion of the cranial base on facial rotation was not as clearly evident in all parameters in children as in adults, and exerted no definite effect on the slope of the palatal plane. In adults, a steeper sloping of the mandibular body, associated with an obtuse gonial angle, was accompanied by a more acute chin angle (CL/ML) and increased anterior height of the lower jaw (Id-Gn). These compensatory and adaptive mechanisms, which promote sufficient contact with the upper jaw, do not operate in early childhood, possibly because of the steeper sloping of the mandibular body at this age (Šmahel *et al.* 1993). The slope of the mandibular ramus (RL/NSL) was more closely related to the height of the maxilla (N-Sp, Pm-NSL) in childhood than in adulthood, but was less closely correlated to mandibular protrusion (S-N-Pg). This could be due to the relatively small size of the lower jaw in children. The other differences, such as the missing correlation between the depth of the maxilla (Ss-Pm) and its protrusion (S-N-Ss), or between the length of the nasal bones (N-Rhi) and their proclination (S-N-Rhi), were not significant. These relations are slight even in adulthood. The weaker correlation between parameters which characterized the rotation of the cranial vault in children *(Table 1)* could be due to lower precision of the measurements in determining certain points (Op) and a different neurocranial configuration.

All the other correlations showed good agreement between the situation in early childhood and in adulthood. The most important characteristic which had an effect on the configuration of the entire cranium was represented by the curvature of the cranial base. This was responsible for facial and cranial vault rotation and the displacement of both jaws backwards or forwards, and exerted an effect on changes in the position of the temporomandibular joint, the slope of the foramen magnum and the slope of the frontal and nasal bone, as well as on a variety of further correlations. Also of importance was the length of the ramus of the mandible, which exerted an effect on the steepness of the mandibular body, vertical jaw relations, the shape and position of the lower jaw and, indirectly, the dentoalveolar inclination of both jaws. An important compensatory mechanism which allowed for adjustment of disordered relations between the protrusion of the mandible and the maxilla in the frontal segment of the teeth was contradirectional change in the inclination of the incisors and the alveolar processes of both jaws (*Figure 5*). The lower jaw played a more important role in developing these impaired relations, but also contributed more considerably to the process of compensation. The close interrelation between the protrusion of both jaws was not due to the identical size of the jaws, but rather to the compensatory mechanisms of the mandible (the inclination of body and ramus), as well as the consistent action of the curvature of the cranial base. The lower facial segment (below the palatal level) showed a certain degree of developmental independence in the vertical direction. The other correlations described above were also in agreement with the relevant data as recorded in adults.

Consistent trends observed both during early childhood and in adulthood showed that intracranial relations as well as compensatory and adaptive mechanisms were governed by certain principles which operated throughout the entire postnatal development period. Therefore, the correlations between the developmental changes of individual characteristics should correspond to correlations between the size of these characteristics at any time during ontogenetic growth. This fact was demonstrated in our patients with a cleft lip and palate. Correlations between changes of the investigated variables during certain periods showed a similar character to correlations between the size of these variables as determined at the end of the study (Machová 1988). Another study disclosed the similarity of correlations between the size of certain selected characteristics at the age of 10 and their subsequent changes up to the age of 15 (Šmahel, Müllerová 1994a, b). The first observation confirmed that the situation determined at a given age represented the result of earlier development, while the second proved that subsequent development proceeded according to the same principles. Our conclusions were confirmed by Björk (1955) in a study of a normal population. He obtained the same correlation coefficients in developmental changes between the ages of 12 and 20 as in an assessment of a cross-sectional study at the age of twenty. The character of intracranial correlations recorded at a certain developmental stage thus definitely reflected the antecedent development, and allowed prediction of its further progress. Knowledge of the principles governing intracranial relations and adaptive and compensatory mechanisms could therefore be helpful in decoding the previous developmental process, and serve in predicting further development, something which would be of importance, e.g., for orthodontic therapy and jaw orthopedics. It is believed that the essential principles of intracranial processes and relations are valid generally.

So far, there have only been a few studies in the literature devoted to interrelations between individual cranial components, and these mostly include only limited numbers of characteristics. No study deals with the situation in early childhood or a comparison of the results obtained with data reported for adults. This is most probably due to the difficulties associated with collecting a large number of roentgenograms of very young normal individuals.

The first results of the study of cranial associations were reported by Björk (1955), who showed that an acute angle of the cranial base led to posterior rotation of the neurocranium, forward displacement of the jaws and a reduced slope of the foramen magnum, the frontal bone and the height of the cranial vault. An obtuse angle exerted the opposite effect. Anderson and Popovich (1983), in a comparison of individuals with markedly obtuse and acute angles of the cranial base, recorded a larger height of the neurocranium, a smaller height of the cranial vault and an anteroinferior displacement of the temporomandibular joint in the case of an acute angle. The length of the neurocranium was not affected by the curvature of the cranial base, as was also confirmed by Lewis and Roche (1977). In another study, Anderson and Popovich (1989) recorded a smaller protrusion of the lower jaw in the presence of a more obtuse angle of the base, as well as the association of a shorter mandibular ramus with a more obtuse gonial angle. The flexion of the cranial base exerted no effect on the slope of the mandibular ramus. Kerr and Adams (1988) reported that a smaller angle of the base was accompanied by a larger protrusion of the upper and lower jaw, with a simultaneous reduction of the angle of sagittal jaw relations due to the larger protrusion of the mandible.

The most comprehensive study heretofore on craniofacial associations in adults was performed by Solow (1966). He used correlation coefficients of all combinations to assess 88 body, cephalometric, roentgencephalometric and odontometric characteristics. Comparison of the interrelations between those parameters which were also determined in our study showed that his results were in good agreement with the data recorded in our series of adult males (Šmahel, Škvařilová 1988). He observed, in harmony with our results, a positive interrelation between the curvature of the cranial base and the prognathism of both jaws, the capability of the dentoalveolar component of the jaws to compensate for deviations in sagittal jaw relations, and a number of other interrelations. However, he failed to demonstrate a significant correlation between the length of the mandibular body and ramus. Solow did not include in his analysis topographic correlations where the relation between individual characteristics was due in part to a shared common reference point or line in both variables. Although these correlations do not characterize an exclusively biological coordination, their precise distinction from non-topographic correlations is hardly possible (Šmahel, Škvařilová 1988). Characteristics related to points situated in close proximity to one another or referring to the same structure, e.g., the cranial base, have similar attributes. Because of the high integration of cranial structures, numerous craniofacial correlations include a larger or smaller portion of variance produced by shared common components or mediated by certain other structures. However, in practice, whether in orthodontic therapy or anthropological reconstruction, these facts are not of major importance. The correlation coefficients reflect the actual situation within the skull, and characterize intracranial relations and compensatory mechanisms.

In some additional studies, the relations between individual cranial characteristics were investigated. The largest number of studies were aimed at the dentoalveolar compensatory processes already described by Björk (1947). Numerous authors have continued to investigate these mechanisms up to the present time (Björk, Palling 1954, Steiner 1959, Corelius, Linder-Aronson 1976, Solow 1980, Lundström, McWilliam 1984, Casko, Shepherd 1984 *et al.*). They have showed that retrusion of the mandible is associated with a more lingual inclination of the upper incisors, and a more marked labial inclination of the lower incisors, and vice versa. The authors last-named above proved that mandibular retrognathia was accompanied by a steeper sloping of the mandibular body and the occlusal plane. Bibby (1980) described identical compensatory processes affecting the position of the incisors, and observed that mandibular retrognathia in the normal general population was, on average, due to retrusion of the mandible and progenia due to retrusion of the maxilla, not protrusion of the lower jaw. We recorded a similar situation in adults (Šmahel, Škvařilová 1988), while in early childhood both anomalies were produced predominantly by the lower jaw. At this age retrusion of the maxilla is uncommon. However, in the normal general population the protrusion of both jaws is mostly in good agreement, and the correlation coefficients vary around 0.8 (Varjanne, Koski 1982). All these observations are consistent with our results. Individual correlation coefficients have also occasionally been mentioned in other cephalometric studies, or in classic anthropometric papers (Strádalová 1977).

The results confirmed that even single correlation coefficients could illustrate certain compensatory processes and adaptive mechanisms taking place within the developing skull. These observations could be applied in orthodontic therapy and jaw orthopedics, which are based on adaptive mechanisms. However, multiple correlation coefficients are indispensable for more efficient use and the prediction of therapeutic results, as an appropriate combination of characteristics allows the attainment of values required for prognostic assessment. These calculations will be discussed in another study (Šmahel *et al.* 1997). Our results further disclosed that the character of intracranial relations and the principles on which they were based showed an agreement in their main features as recorded in childhood and in adulthood. Comparison with data from the literature likewise revealed similarities between distinct ethnic populations, e.g., in dolichocephalic leptoprosop Nordics (Solow 1966) and brachycephalic euryprosop Middle Europeans (Šmahel, Škvařilová 1988). Thus intracranial relations and compensatory mechanisms were not substantially affected by the type of skull. Some similar observations were reported in other primates as well. An effect of curvature of the cranial base on protrusion of the jaws identical to that in humans was reported in gorillas by Björk (1955), and the same compensatory relation between the angle of the cranial base and the angle formed by the clivus and the plane of the foramen magnum was found in macaca monkeys by Doskočil (1962). Certain interrelations could therefore be universal, occurring in all primates. It would be interesting to investigate whether these basic features might be present in the skulls of all mammals. Thorough knowledge of general principles, as well as principles characterizing individual species and affecting intracranial relations, could allow the possibility of transposing the results of cephalometric studies on animals to humans. It must therefore be considered necessary to continue comprehensive studies both on animals and on humans, in order to improve our knowledge, which is at present only scanty. Without thorough knowledge, the results obtained on experimental animals and described in numerous reports (reviewed by Sarnat 1988) cannot be applied to humans. An understanding of the causality and extent of these relations requires further study. Finally, comprehensive knowledge could be used in anthropological reconstructions not only of recent humans but also of their evolutionary ancestors.

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