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**EXTERNAL AND INTERNAL CRANIAL BASE  
A CROSS SECTIONAL STUDY OF GROWTH AND OF  
ASSOCIATION IN FORM**

*by*

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**INTRODUCTION**

In cephalometric roentgen analysis the reference line most frequently applied in the anterior cranial base, is the nasion-sella line, *NSL* (*Brodie* 1941, *Björk* 1947, 1955, *Lindegård* 1953, *Ricketts* 1955, and others). The stability of this line during growth relies on the two reference points nasion and the center of sella turcica.

The stableness of the *sella* point in relation to the sphenoid bone during growth is difficult to prove and not known, although *Baume* (1957) made an attempt histologically to demonstrate a change in position of sella in relation to the body of the sphenoid bone during growth of the Rhesus monkey.

*Nasion* moves forward during growth in relation to the sphenoid bone by increase in length of the anterior cranial fossa as well as by increase in thickness of the frontal bone. *Keith & Champion* (1922), on the basis of investigations of skull material, thought that generally nasion also takes an upward course during its forward growth. *Björk* (1955) found no general tendency in the change of the nasion level during adolescence as estimated from a longitudinal study on roentgenographic material. *Ford* (1958) gained no definite evidence of an upward movement of nasion from studies on groups of cranial material involving different ages from infants to adults. *Björk* (1958 b) presents individual cases which reveal that nasion may ascend as well as

descend during growth, depending either on a change in position of the different skeletal units of the cranial base or resulting from the growth increment at the fronto-nasal articulation.

The deflective shape of the cranial base, expressed in terms of degrees of the angle nasion-sella-basion (*n-s-ba*), represents the form of the *external* cranial base, and this angle can easily be measured on profile roentgenograms. Different methods for determining the *internal* shape of the cranial base from profile roentgenograms have been employed (*Pankow 1951, Moss & Greenberg 1955*, and others). Based on the early development of the anterior cranial fossa, *de Coster (1951)* suggested a reference line from tuberculum sellae through the cribriform plate to the internal surface of the frontal bone. *Björk (1955)* observed that the contour of the cribriform plate remained nearly unchanged during the adolescent period, but some variations were noticed in the formative development of tuberculum sellae and jugum sphenoidale during growth in some cases. As reference point in the anterior cranial base *Björk* therefore applied ethmoidale, which is a landmark on the cribriform plate. Through the points ethmoidale and sella the reference line, *ESL*, was drawn (*Björk 1958 b*), and the angle ethmoidale-sella-basion (*eth-s-ba*) was employed in measuring the internal form of the cranial base. This procedure is in agreement with the fact that the cribriform plate is the first component of the anterior cranial base to reach its final developmental state (*Scott 1955, Ford 1958*). The purpose of the present investigation is to find the covariation between the external and the internal form of the cranial base and, if possible, to uncover some general tendencies in growth of the various components of the above mentioned regions of the skull.

#### MATERIAL

The material consists of 464 cephalometric profile roentgenograms of Danish males ranging from 3 to 25 years of age. The head plates were made from subjects having different types of occlusion, although cases disclosing pathologic facial and cranial skeletal development were omitted. The work was carried out at the Orthodontic Department of the Royal Dental College, Copenhagen. The major part of the material was collected from

the files of this department, but in order to cover a wider range of age the sample was supplemented with children of kindergarten age and with an adult group of students, varying in age from 19 to 25. The age distribution of the whole sample appears from Table 1. The age grouping has been made in such a way that the three years group comprises individuals having passed the age of three, but not the age of four and so on. Except for the youngest group there are thirty or more individuals in each group.

#### METHOD

The profile roentgenograms were obtained by using the head holder described by *Björk* (1958 a). The focus-median plane distance is kept at 180 cm and the median plane-film distance at 10 cm. The measurements are submitted without correction of magnification which is calculated to about 5.6 per cent in the median plane.

#### Registration

The analysis of the present material was based on linear and angular measurements registered directly on the head plates. Attempts were made to attain roentgenograms of high quality, and exposures showing blurred contours have not been included in the analysis. On the 464 films selected the points and lines mentioned in this paper could be localized without difficulty.

Most of the reference points used, such as nasion, ethmoidale, basion, the anterior nasal spine and gnathion, and the reference lines through these points, are situated in the midsagittal plane. However, other landmarks, such as the uppermost point in the roof of the orbital cavity and pterygomaxillare, are projections into the midsagittal plane. This is also the case with the bilateral contours of the inferior margin of the body of the mandible. Double contours, especially of the mandibular angle, the ramus and the roof of the orbital cavity, frequently appear in lateral roentgenographic projections, and in such cases the point or the line lying half way between them is employed for registration.

Definitions of cephalometric roentgenographic reference points and reference lines, as listed below, conform with the definitions

used at the Royal Dental College, Copenhagen (*Björk 1958 a*). In addition, the position of the uppermost point of the roof of the orbital cavity and the position of the foremost point of the nasal bone are registered. Measuring points and reference lines appear from Fig. 1.

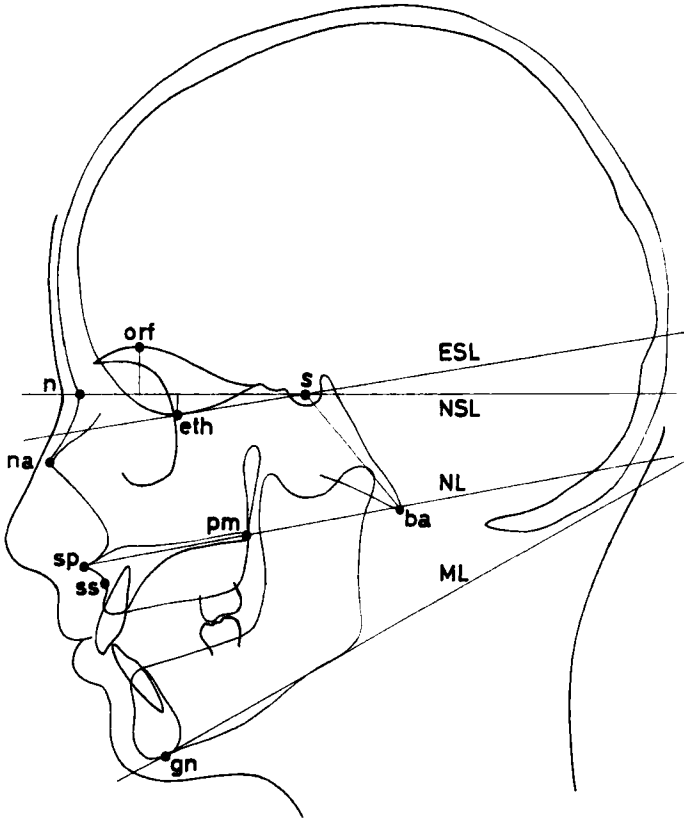


Fig. 1. Reference points and reference lines used on lateral cephalometric x-ray films.

#### Reference points

**Basion (*ba*):** The perpendicular projection of the anterior border of foramen magnum (endobasion) on a tangent through the lower contour of the foramen.

**Ethmoidale (*eth*):** The lowest median point of the contour of the anterior cranial fossa, corresponding to the cribriform plate of the ethmoid bone.

*Gnathion (gn)*: The lowermost point of the mandibular symphysis.

*Nasal apex (na)*: The most protruding point of the nasal bone.

*Nasion (n)*: The most anterior point of the nasofrontal suture.

*Orbital roof (orf)*: The uppermost point in the roof of the orbital cavity.

*Pterygomaxillare (pm)*: A point which represents the dorsal surface of the maxillary body at the level of the nasal floor. The point is localized on the dorsal contour of the maxilla, where this contour is crossing that of the hard and soft palate.

*Sella (s)*: The center of the bony crypt forming the sella turcica. The surface of the sella turcica is determined independently of the contours of the clinoid processes, and is limited upward by a line from tuberculum sellae to dorsum sellae. The center is defined as the midpoint of the greatest diameter from tuberculum sellae.

*Spinal point (sp)*: The apex of the anterior nasal spine.

*Subspinale (ss)*: The deepest point of the anterior contour of the maxillary alveolar process (corresponding approximately to the apical zone).

#### Reference lines

*Ethmoidale-sella line (ESL)*: The line drawn through ethmoidale and sella.

*Mandibular line (ML)*: The tangent to the base of the mandibular body drawn through gnathion.

*Nasal line (NL)*: The line drawn through the spinal point and pterygomaxillare. It represents the floor of the nasal cavity and the base of the maxilla.

*Nasion-sella line (NSL)*: The line connecting nasion and sella. It represents the anterior cranial base.

*Sella-basion line (s-ba)*: The line connecting sella and basion. It represents the medial part of the posterior cranial base.

All measurements, linear as well as angular, are read to the nearest half of a millimeter and to the nearest half of a degree respectively. On the basis of the aforementioned reference points and reference lines the following linear and angular measurements are employed:

*Linear measurements* (Table 1).

1. *n—s*: The external length of the anterior cranial base measured from nasion to sella.
2. *Frontal bone thickness*: The distance measured from nasion to the nearest point on the internal contour of the frontal bone.
3. *Anterior cranial fossa length*: The internal length of the anterior cranial base, which arises as the difference between the *n—s* length and the frontal bone thickness.
4. *s—ba*: The length of the medial posterior cranial base measured from sella to basion.
5. *eth—NSL*: The perpendicular distance from ethmoidale to *NSL*. The value of this measurement is positive when ethmoidale is situated below *NSL* and negative when ethmoidale is situated above *NSL*.
6. *orf—NSL*: The perpendicular distance from the uppermost point of the roof of the orbital cavity to *NSL*.
7. *eth—NL*: The perpendicular distance from ethmoidale to *NL*.

*Angular measurements* (Table 2).

1. *n—s—ba*: The external cranial base angle.
2. *eth—s—ba*: The internal cranial base angle.
3. *eth—s—n*: The angle between the two reference lines *ESL* and *NSL*.
4. *NSL/NL*: Rotation of the maxilla defined as the angle between *NSL* and *NL*.
5. *ESL/NL*: Rotation of the maxilla defined as the angle between *ESL* and *NL*.
6. *NSL/ML*: Rotation of the mandible defined as the angle between *NSL* and *ML*.
7. *ESL/ML*: Rotation of the mandible defined as the angle between *ESL* and *ML*.
8. *s—n—ss*: Maxillary prognathism.
9. *s—n—na*: Protrusion of the nasal bone.

## PART I. GROWTH CHANGES

Cross sectional growth studies involve several problems, limiting their application. By this method it is possible to acquire an understanding of the central growth tendency on the basis of the mean values at different age levels, but this tendency can only be approximated. The first reason is that *the standard error of the mean* is large when the number of individuals in each group is small. Secondly, the study comprises individuals in various age groups, which may differ biologically in many respects, whereby the group mean values are attended with *systematic errors*, which may not be included in the standard errors. The third reason is that each age group holds individuals with one year's *dispersion of age*, which also may influence the group mean values.

Cross sectional data naturally give no information of the individual variation in growth. A more exact study of the facial growth would have to be carried out on longitudinal material. However, as will be shown in this paper, indicative results are obtained also from cross sectional data.

In the following, attention will be directed towards the linear growth of cranial base dimensions, and subsequently changes in form of the cranial base will be discussed.

**Dimensions** (Table 1)

The measurement most commonly used to represent *the length of the anterior cranial base* is the distance  $n-s$ . This external length of the cranial base consists of two elements, the length of the anterior cranial fossa and the thickness of the frontal bone. On profile roentgenograms an exact anatomical subdivision in these two parts cannot be accurately made, as is the case in studies of cranial material (Ford, 1958). Thus, on roentgenograms the *thickness of the frontal bone* is measured directly, and the *length of the anterior cranial fossa* is calculated by subtracting the frontal bone thickness from the  $n-s$  distance. This indirect measurement was found to serve the purpose of this work.

The growth in thickness of the frontal bone approximates a linear function during the entire period from 3 years to adult

Table 1. Linear measurements in millimeters.

Age	Number of cases	1 n-s		2 Thickness of frontal bone		3 Length of anterior cranial fossa		4 s-ba		5 eth to NSL		6 orf to NSL		7 eth to NL	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
3	13	60.5	2.6	7.3	2.0	53.2	2.6	35.5	2.6	2.4	1.3	13.5	2.1	33.1	1.9
4	30	62.7	2.6	7.9	1.3	55.2	3.2	38.5	1.6	2.4	1.6	14.2	2.0	35.7	2.2
5	40	64.7	2.2	8.3	1.4	56.3	2.5	39.2	1.9	2.5	1.3	14.1	1.4	37.0	2.4
6	31	66.0	2.2	9.2	1.8	56.9	2.4	39.5	3.2	2.7	1.8	13.5	1.7	37.7	2.0
7	31	66.8	3.0	9.8	1.8	57.0	3.2	41.0	3.8	3.0	1.7	13.1	1.4	39.4	2.6
8	43	66.4	2.4	9.9	2.1	56.5	3.1	41.4	3.8	2.9	1.6	13.4	2.1	39.7	2.1
9	40	67.8	3.1	10.3	1.8	57.5	3.1	42.5	3.2	3.3	1.6	13.3	1.7	40.3	2.8
10	61	68.4	2.8	11.0	2.0	57.5	2.9	44.0	2.9	3.4	1.9	13.2	1.6	41.7	2.7
11	49	68.7	2.7	10.8	2.3	57.9	2.6	43.8	3.6	3.7	1.7	13.3	1.5	41.6	2.9
12	32	68.6	3.5	11.8	2.7	56.8	3.7	44.3	3.3	3.0	2.2	13.5	1.8	43.2	2.5
13	30	69.8	4.0	11.9	2.2	57.9	3.6	46.2	2.7	3.6	1.6	12.9	1.8	43.5	3.3
14	30	69.7	2.9	12.7	1.7	56.9	3.1	46.7	3.1	3.3	2.0	13.2	1.6	43.2	2.5
19-25	34	73.7	3.7	16.4	2.7	57.3	3.4	48.5	2.7	2.4	2.2	14.4	1.5	48.1	2.9

M = arithmetical mean.

SD = standard deviation.

age, as demonstrated by the distance curve for this dimension (Fig. 2). This finding agrees with the results presented by Roche (1953), in which the growth in thickness of the frontal bone was calculated on roentgenograms from a longitudinal material.

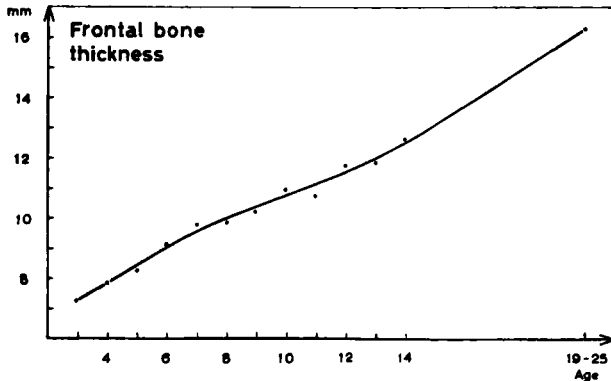


Fig. 2. Distance curve showing the increase of frontal bone thickness by age measured at nasion.

The growth of the anterior cranial fossa has an entirely different course, with a marked increase in length up to 7 years of age, after which only insignificant enlargement is found up to the age of puberty (Fig. 3).

The growth curve of the total length of the anterior cranial base from nasion to sella (Fig. 4) demonstrates a type of growth which is composite of the two growth curves described previously, rising comparatively sharply until 7 years of age, whereafter an almost linear and slow rise goes on for the remaining developmental period.

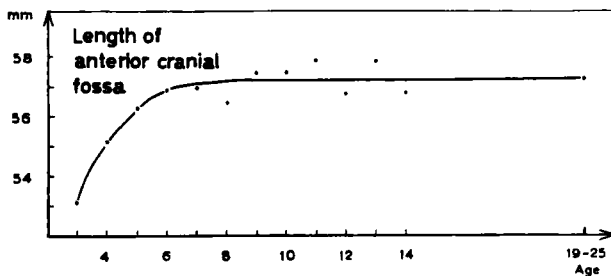


Fig. 3. Distance curve showing the increase in length of the anterior cranial fossa by age.

Like the nasion-sella length, the *posterior cranial base (s—ba)*, which is measured in the median sagittal plane and mainly constitutes the clivus, shows a continuous enlargement until full development is accomplished (Fig. 5).

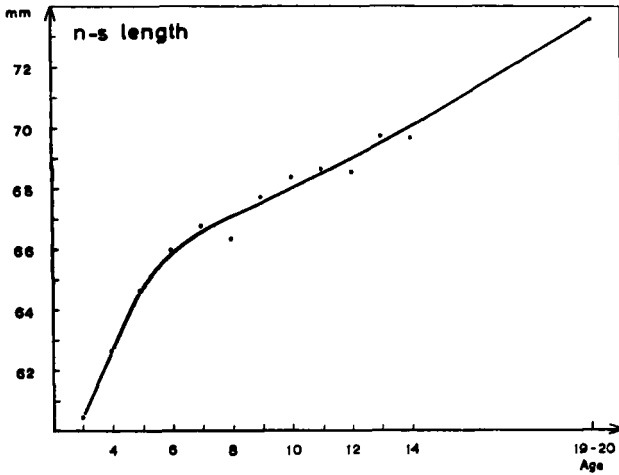


Fig. 4. Distance curve showing the increase of the nasion-sella length by age.

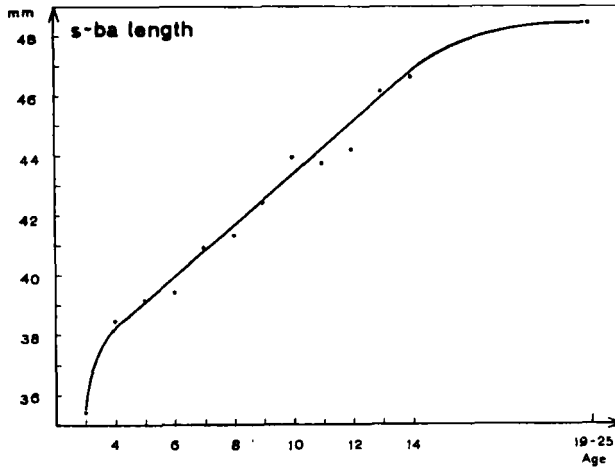


Fig. 5. Distance curve showing the increase of the posterior cranial base length by age.

As regards the mechanism of growth these curves reveal that the periosteal apposition on the external surface of the frontal bone is a nearly continuous process during the entire growth period, while the sutural growth in length of the anterior cranial fossa largely is finished at the age of 7 to 8 years.

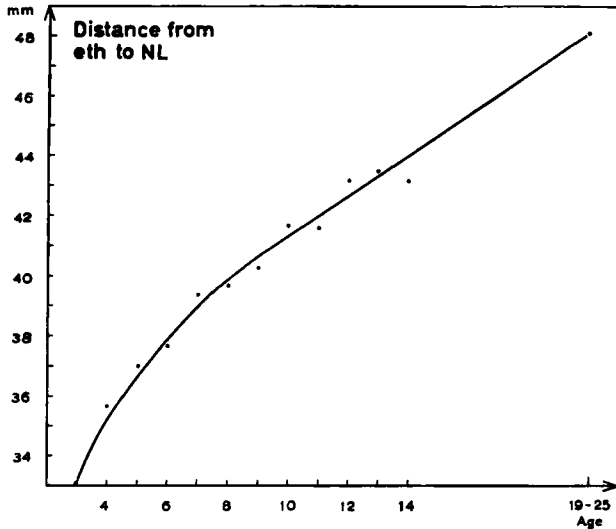


Fig. 6. Distance curve showing the increase of upper facial height by age.

After this developmental stage only minute sutural growth takes place, a process which ceases entirely as puberty is reached.

The growth increase of the posterior cranial base, expressed here by the length of the clivus, reveals that the chondral growth of the sphenoccipital synchondrosis generally goes on nearly up to adult age (cf. *McKern & Stewart, 1957*).

The abovementioned growth curves as well as that in Fig. 6, are smoothed, as scattering of group mean values occurs. However, the qualitative difference between the diagrams is of such a nature that the tendency becomes quite apparent. The path of the curves corresponds well to the roentgenologic data by *Roche (1953)* and to data calculated by *Ford (1958)* from cranial material. An accurate estimation of the annual fluctuation of growth increase can only be carried out from velocity curves constructed

on the basis of longitudinal material. Therefore a discussion of this kind of changes is not within the scope of the present paper.

The stability of the nasion—sella line (*NSL*) in relation to the median contour of the anterior cranial fossa, is investigated by measuring the perpendicular *distance from the nasion—sella line to ethmoidale* (cribriform plate). Björk (1955) found this dimension to remain constant from 12 to 20 years of age in Swedish males. His study was carried out on longitudinal material, and ethmoidale was calculated to be situated on an average  $2.2 \pm 0.15$  mm below the nasion—sella line. In the present material the corresponding mean value of the total sample is  $3.0 \pm 0.08$  mm. The difference between these two calculations, 0.8 mm, is significant as based on the standard errors of the means. The dissimilarity which is very small, may arise from systematic error in locating the reference point, ethmoidale, by the different investigators.

The age changes for linear dimensions measured appear in Table 1, and the distance from ethmoidale to *NSL* is given in Column 5. The probability that the differences between mean values of the age groups arise by chance for this dimension is less than one per cent, calculated by analysis of variance. The means for the youngest and the oldest groups are of the same magnitude, but higher values appear at intermediate age levels. Whether this difference is due to the ageing or not is questionable, as the divergence is small and may be due to systematic errors, a problem which cannot be solved by the probability test as mentioned above. The interpretation of these findings is therefore that the nasion—sella line remains in a rather stable position in relation to the anterior cranial fossa during growth from 3 years of age to final development.

The stableness of the nasion—sella line in relation to the roof of the orbital cavity is also examined. In order to do this the perpendicular *distance from the nasion—sella line to the uppermost point of the orbital cavity* is investigated. From the total material this dimension is calculated to  $13.5 \pm 0.08$  mm on an average. As indicated by Table 1, Column 6, no significant fluctuation is observed of group mean values. (The probability, that the mean values differ merely as a result of chance has been calculated by analysis of variance to be between 1 and 5 per

cent). A noticeable difference from 3 years to adult age is therefore not demonstrated.

The findings described above indicate that the distances *orf*—*NSL* and *eth*—*NSL* generally remain rather constant after the age of three. If in the course of the growth period nasion had a central tendency to move upward in relation to the internal anterior cranial base, both these distances would be expected to change, which they do not do. However, this does not mean that a vertical displacement of nasion does not take place in individual cases. *Björk* (1958 b) demonstrated upward as well as downward changes in the level of nasion as related to the anterior cranial fossa in the individual. The extent of the vertical movement of nasion in the individual should be examined on longitudinal material covering the entire developmental period.

*Meredith* (1958) studied growth of the upper anterior facial height, nasion—anterior nasal spine, based on a longitudinal material from 5 to 12 years of age. As nasion individually may move upward as well as downward during growth, attempt has been made to adopt a measurement of the upper facial height which is not influenced by vertical displacement of nasion. A dimension which fills this purpose is the perpendicular distance from ethmoidale to the nasal line (Tab. 1, Col. 7). The distance curve of this upper facial height (Fig. 6) reveals a continuous growth of decreasing intensity as adult age is approached.

#### Form (Table 2)

As nasion is a reference point on the external cranial base, the shape of the cranial base, measured through the angle *n—s—ba*, consequently serves as an expression of the *external form* (*Björk* 1951, 1955, *Lindegård* 1953, *Ricketts* 1955). The *internal form* has also been examined by various authors (*Pankow*, *Moss* and others). *Björk* (1958) employed the angle *eth—s—ba* in measuring the internal form of the cranial base. In the present study a comparison of the development of the internal and the external form of the cranial base has been carried out. In Table 2, Column 1 the angle nasion—sella—basion and in Table 2, Column 2 the angle ethmoidale—sella—nasion are calculated at successive age levels. The group means of both angles fluctuate, and the two

Table 2. Angular measurements in degrees.

Age	Number of cases	1		2		3		4		5		6		7		8		9								
		n-s-ba	M	SD	eth-s-ba	M	SD	eth-e-n	M	SD	NSL/NL	M	SD	ESL/NL	M	SD	NSL/ML	M	SD	ESL/ML	M	SD	s-n--ss	M	SD	s-n--na
3	13	133.1	4.2	129.3	4.7	3.8	2.0	5.6	2.1	1.8	3.0	37.6	3.8	33.7	4.1	80.5	3.0	103.8	6.6							
4	30	133.4	3.8	130.1	3.8	3.3	2.4	7.0	2.6	3.7	3.0	36.3	4.1	33.0	5.0	79.4	2.6	102.9	4.8							
5	40	132.1	4.4	128.7	5.2	3.4	1.9	6.6	2.9	3.1	3.5	34.9	5.3	31.4	5.8	80.2	3.3	104.1	5.1							
6	31	131.8	5.7	128.3	6.3	3.5	2.5	6.8	3.3	3.3	4.2	34.0	4.3	30.5	5.0	79.1	3.4	102.9	6.8							
7	31	133.0	4.0	128.6	4.6	4.3	2.6	6.6	3.6	2.3	3.6	32.6	5.5	28.3	5.1	80.0	3.9	106.5	4.8							
8	43	131.0	5.1	126.9	5.0	4.2	2.4	6.3	3.4	2.2	3.9	33.8	5.5	29.7	6.1	80.7	3.2	107.0	6.1							
9	40	130.7	4.7	126.3	4.6	4.4	2.2	5.1	2.8	0.7	3.5	32.6	4.1	28.2	4.6	81.1	3.3	103.8	5.3							
10	61	130.4	4.7	125.9	5.2	4.5	2.7	6.2	4.8	1.7	3.5	34.3	5.5	29.8	6.1	79.8	3.4	110.0	5.5							
11	49	131.7	4.6	126.5	4.5	5.2	2.6	7.1	3.1	1.9	3.7	32.9	5.1	27.7	5.5	80.4	3.5	109.4	6.0							
12	32	130.7	5.0	126.5	5.3	4.2	3.2	7.5	3.0	3.3	4.4	35.9	6.3	31.7	7.4	80.6	4.1	109.9	6.0							
13	30	131.5	3.2	126.4	3.8	5.2	2.2	7.2	3.4	2.0	3.9	32.1	6.8	26.9	7.2	79.9	3.9	110.0	6.6							
14	30	131.5	3.9	126.4	4.4	5.2	2.7	7.2	3.7	2.0	5.0	32.1	7.4	26.9	7.9	80.2	3.7	114.0	6.2							
19-25	34	131.2	4.8	128.1	4.5	3.2	2.9	6.2	3.2	3.1	3.1	27.5	5.8	24.3	6.0	81.0	3.9	119.3	7.0							

M = arithmetical mean.

SD = standard deviation.

Table 3. Angular measurements in degrees comprising the total sample of 464 cases.

	Angles	1 M	2 SE	3 SD	4 P
1	<i>n—s—ba</i>	131.5	0.21	4.6	> 0.05
2	<i>eth—s—ba</i>	127.3	0.21	4.9	< 0.01
3	<i>eth—s—n</i>	4.2	0.12	2.6	< 0.01
4	<i>NSL/NL</i>	6.6	0.16	3.4	> 0.05
5	<i>ESL/NL</i>	2.4	0.18	3.8	< 0.05
6	<i>NSL/ML</i>	33.5	0.85	5.8	< 0.001
7	<i>ESL/ML</i>	29.3	0.93	6.3	< 0.001
8	<i>s—n—ss</i>	80.2	0.16	3.5	> 0.05
9	<i>s—n—na</i>	108.7	0.33	7.2	< 0.001

M = arithmetical mean. SE = standard error of the mean. SD = standard deviation. P denotes the probability of differences between age groups being due to chance only.

angles present a slight decreasing tendency with age. The analysis of variance indicates (Tab. 3, Col. 4) that the probability of differences between group mean values of the angle *n—s—ba* merely due to chance exceeds 5 per cent, i.e. the group means are not significantly different. The probability, that differences between group mean values of the angle *eth—s—ba* are due to chance, is less than 1 per cent, which is significant. The aforementioned data therefore seem to indicate that the internal cranial base generally flattens out in childhood, but definite conclusions will not be drawn from this cross sectional material, because the differences between the group means are small and because the calculation is based on different children in each age group, why the differences may be due to the systematical errors in the sampling.

The angle *eth—s—n* formed by intersection of the two reference lines *NSL* and *ESL* is seen in Table 2, Column 3, and the same angle calculated from the total material appears in Table 3, Row 3. Based on the standard error of the mean a significant difference is found between group means, but here again the differences are small and may be caused by the composition of the material as discussed above.

In addition, Table 2 presents mean values at each age level of

a number of facial angles which are applied in the subsequent covariation analysis. In Table 3 mean values for the total material are demonstrated. The probability, that the group mean values differ merely as a result of chance, is shown in Column 4 of this Table.

From Table 3, Rows 4 and 5 it is apparent that the angle between the nasal line and the anterior cranial base, i.e. the degree of rotation of the maxilla, generally does not change with age on an average no matter which reference line in the cranial base is used, the *NSL* or the *ESL*.

The angle between the inferior surface of the body of the mandible and the anterior cranial base, i.e. the degree of rotation of the mandible, reveals a significant decrease with age as measured to both reference lines, the *ESL* and the *NSL* (Tab. 3, Rows 6 and 7).

The maxillary prognathism remains unchanged in all age groups, while the protrusion of the nasal bone presents a marked and definite increase with age as measured by the angle  $s-n-na$  (Tab. 3, Rows 8 and 9).

Definite conclusions drawn from the findings described above are that an anterior rotation of the mandible takes place and that the nasal bone becomes more protruding with age. These age changes are so strikingly evidenced that they are claimed to exceed the systematical error. Conversely, the remaining angles studied are subjected to reservations, because minor developmental changes of central tendency fail to appear with convincing certainty from cross sectional analysis.

#### PART II. CORRELATIONS (TABLES 4 AND 5)

The problem of primary interest in this analysis is the degree of *coordination between the external and internal form of the cranial base*. This interrelation is a criterion of individual variation in the development of the two forms. When the external and internal cranial base angles,  $eth-s-ba$  and  $n-s-ba$ , behave similarly, correlation between the two is positive and has a high value. Table 4 shows product moment correlation coefficients between the angles  $eth-s-ba$  and  $n-s-ba$  calculated for each particular age group separately. The figures indicate that correla-

Table 4. Correlation between  $n-s-ba$  angle and  $eth-s-ba$  angle at different age levels.

Age	Number of Cases	r
3	13	+ 0.90
4	30	+ 0.79
5	40	+ 0.93
6	31	+ 0.92
7	31	+ 0.82
8	43	+ 0.89
9	40	+ 0.89
10	61	+ 0.85
11	49	+ 0.84
12	32	+ 0.81
13	30	+ 0.82
14	30	+ 0.80
19—25	34	+ 0.81

r = the product moment correlation coefficient.

tion is rather similar at the different age levels, but here again fluctuations may be masked as the analysis is carried out on various groups comprising different individuals.

Correlative estimates of the entire material with the various age groups involved appear in Table 5. The coefficient of correlation between the external cranial base angle,  $n-s-ba$ , and the internal cranial base angle,  $eth-s-ba$ , is found to be + 0.86 for the total sample (Table 5, Row 1). The figure denotes that in individual development the external and internal forms of the cranial base tend to be intimately coordinated. Evaluated by the coefficient of determination ( $r^2$ ), 74 per cent of the variations in form of the cranial base can be explained by this correlation. Although *NSL* on an average serves as a reliable representative of the anterior cranial base, studies of individual development by cephalometric analysis necessitate corrective adjustments of *NSL* to the internal base of the cranium. A method for correction of *NSL* in individual growth analysis has been described by Björk (1958 a).

Variations of the vertical level of nasion in relation to the anterior cranial fossa may be shown from correlative estimates

Table 5. Correlation of external and internal cranial base angles.

	Correlations	r
1	n—s—ba and eth—s—ba	+ 0.86***
2	orf to NSL and eth to NSL	— 0.54***
3	eth—s—ba and eth—s—n	— 0.37***
4	n—s—ba and NSL/NL	+ 0.32***
5	eth—s—ba and ESL/NL	+ 0.48***
6	n—s—ba and NSL/ML	+ 0.18***
7	eth—s—ba and ESL/ML	+ 0.30***

r = the product moment correlation coefficient.

\*\*\* denotes that the probability of r differing from zero is more than 99.9 per cent.

between the perpendicular distances measured from the uppermost point of the roof of the orbital cavity to *NSL* and from ethmoidale to *NSL* (Table 5, Row 2). These two points are situated on either side of *NSL*, and the correlation coefficient between the two dimensions is — 0.54. When *NSL* is positioned at a high level, therefore, its distance from the roof of the orbital cavity will consequently be small, and in case of a low position of *NSL*, a corresponding inverse relation appears.

The question arises as to whether the variation of the vertical level of nasion is coordinated to the form of the cranial base. In order to study this relation the internal cranial base angle, *eth—s—ba*, is correlated to the angle formed by intersection of *ESL* and *NSL*, i.e. the angle *eth—s—n* (Table 5, Row 3). The correlation is — 0.37 and signifies that nasion, which is not common to both angles, tends to move *downward* during growth when the internal cranial base flattens out and *upward* when a deflection of the internal cranial base takes place. This indicates that the deflection of the internal cranial base is partly masked by the position of nasion. Further evidence to support this finding appears in Table 3, where the standard deviation of the cranial base angle is higher when measured internally than externally viz. 4.9 and 4.6 degrees respectively. The error in locating the ethmoidal point affects this correlation in negative direction, but this cannot be expected to account for the entire negative coordination in question. Fig. 7 shows a diagram of this correlation.

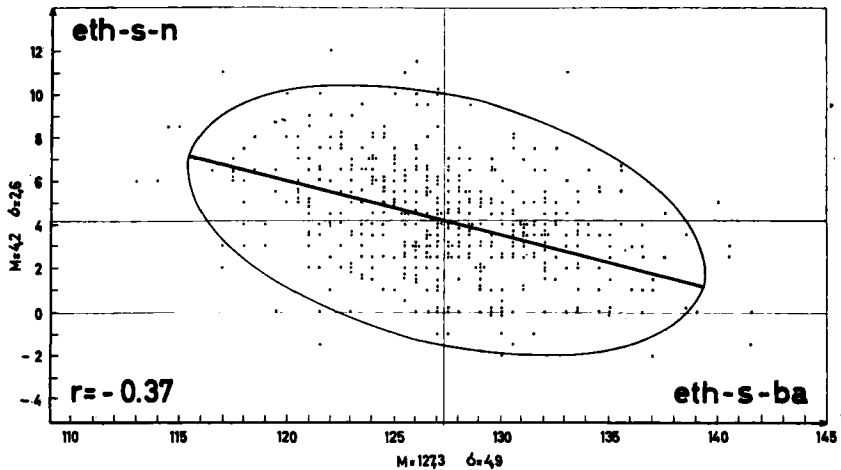


Fig. 7. The negative correlation between the two cranial base angles, ethmoidale-sella-nasion and ethmoidale-sella-basion, illustrated with the 95 per cent contour ellipse and the orthogonal regression line.

The 95 per cent contour ellipse and the orthogonal regression line, which is the main axis of the ellipse, illustrate the distribution.

Based on the preceding findings it may be concluded that the internal angle of the cranial base is a better expression of form, than is the external angle. Finally, the vertical change of nasion with growth partly compensates for changes in the internal form of the cranial base.

Since both reference lines, *NSL* and *ESL*, individually may alter their position, as the correlation is less than 1.0, the question must be raised as to which one of the two lines is the more suitable for the purpose of investigating developmental covariations between the cranial base and the facial skeleton. In Table 5, Row 4, the correlation coefficient between the external cranial base angle, *n-s-ba*, and the *angle of rotation of the upper jaw, NSL/NL*, is presented. The value of *r* is calculated at +0.32, which agrees with investigations performed by *Lindegård* (1953) who found the corresponding correlation coefficient to amount to +0.33. If this value is compared to the correlation coefficient between the internal cranial base angle and the maxillary rotation, which is determined as the correlation between *eth-s-ba*

and *ESL/NL*, the result is an increased coefficient of correlation, viz. +0.48 (Table 5, Row 5).

An appraisal of the coordination between the form of the cranial base and the *angle of rotation of the lower jaw* (Table 5, Rows 6 and 7) shows that the correlation coefficient between the angles *n—s—ba* and *NSL/ML* is as small as +0.18 though the correlation coefficient rises to +0.30 when coordination is calculated between *eth—s—ba* and *ESL/ML*. Because sella is common to *NSL* and *ESL*, the preceding observation indicates that individual upward or downward movement of nasion reduces the estimated coordination between cranial base form and facial rotation. Therefore, coordination is more intimate when calculated on the basis of *ESL* as reference line of the anterior cranial base.

As a conclusive result of these findings *ESL* should be preferred as reference line to *NSL* in correlative studies of coordination between deflection of the cranial base and the rotation of the facial skeleton.

#### SUMMARY

A comparative study of the external and internal form of the cranial base was carried out from profile roentgenograms of 464 Danish males. The material comprises individuals from 3 to 15 years of age and adults varying in age from 19 to 25 years. The investigation is divided in two constitutive chapters. In the first part the general growth tendencies of various dimensions and angles of the cranial base are analyzed, and in the second division coordinations between external and internal form of the skull base are studied.

#### Growth changes (Tables 1 and 2. Figs. 2—6)

In profile roentgenograms the external length of the anterior cranial base is divided into two components: the length of the anterior cranial fossa and the thickness of the frontal bone. The frontal bone thickness is recorded separately, and the length of the anterior cranial fossa is indirectly estimated by subtracting the thickness of the frontal bone from the nasion—sella distance. The length of the posterior cranial base is measured in the

median plane from sella to basion. Distance curves of the different dimensions of the cranial base are calculated and give the following results:

1. Growth of the frontal bone thickness is a continuous and linear process from 3 years to adult age.

2. The anterior cranial fossa reveals a marked increase in length until approximately 7 years of age, succeeded by a slight increase in length which goes on to the age of puberty.

3. Growth of the external length of the anterior cranial base from sella to nasion is a combination of the aforementioned two types of growth presenting a relatively marked length increase up to 7 years and thereafter almost linear enlargement until adult age.

4. The posterior cranial base shows an approximately linear increase up to adult age.

Regarding the form of the cranial base and some related structures, the following results appear:

5. The external form of the cranial base, measured through the angle  $n-s-ba$ , as well as the internal form of the cranial base, recorded by the angle  $eth-s-ba$ , on an average stay unchanged from 3 years to adult age. Minute fluctuations cannot be evaluated from the present material.

6. The tip of the nasal bone displays a continuously increasing protrusion of about 16 degrees from 3 years to adult age when recorded by the angle  $s-n-na$ .

7. Both the nasion—sella line and the ethmoidale—sella line are applied as reference lines of the anterior cranial base (Fig. 1). Attempts have been made to test the stability of the former as related to the latter during growth by utilizing the perpendicular distance from ethmoidale to *NSL*. This distance is nearly constant on an average in the total period of growth from 3 years to adult age. Similarly it is found that the perpendicular distance from the roof of the orbital cavity to *NSL* remains nearly unchanged with age. This indicates that nasion during growth generally moves forwards in the length direction of the anterior cranial fossa. Individually, however, it may be anticipated that nasion may ascend as well as descend during growth, a finding which is evidenced by the subsequent correlative investigations.

## Covariations (Table 5)

8. Coordination between the external and internal form of the cranial base is calculated as the correlation between the angles  $n-s-ba$  and  $eth-s-ba$ . The correlation coefficient of the total material is  $+0.86$ . Grossly the external and internal forms of the skull base behave similarly, but relatively large individual deviations may occur.

9. The question of how the vertical level of nasion is coordinated to the internal form of the cranial base is studied. In relation to the anterior cranial fossa, nasion moves upwards when extensive deflection of the internal cranial base is found and downwards when the cranial base flattens out. This seems to indicate that the external form of the cranial base recorded by employing nasion partly masks the internal form of the base of the skull.

10. It appears from this study that rotation of the upper face as well as of the lower face is more intimately coordinated with the form of the cranial base when *ESL* is applied as reference line than when *NSL* is applied. Correlative investigations between the form of the cranial base and the face, therefore, should be founded on the internal form of the cranial base.

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## RESUME

## BASE CRANIENNE EXTERNE ET INTERNE.

## Croissance moyenne et rapports de forme.

Une comparaison entre la forme externe et la forme interne de la base crânienne a été exécutée sur des radiographies de profil de 464 sujets danois du sexe masculin dont un groupe âgé de 3 à 15 ans et un groupe d'adultes de 19 à 25 ans. Les recherches sont subdivisées en deux parties. La première partie analyse la tendance générale de croissance des différentes dimensions et des différents angles de la base du crâne, et la deuxième partie examine les rapports entre la forme externe et la forme interne de la base du crâne.

**Changements dans la croissance** (Tableaux 1 et 2. Figures 2—6)

La longueur externe de basis cranii anterior est subdivisée sur les radiographies en deux éléments, la longueur de fossa cranii anterior et l'épaisseur d'os frontale. L'épaisseur de l'os frontale est mesurée séparément et la longueur de fossa cranii anterior est appréciée indirectement en soustrayant l'épaisseur d'os frontale de la distance nasion-sella. La longueur postérieure de la base du crâne est mesurée dans le plan médian, de sella à basion. Les courbes de distances de ces différentes dimensions de la base crânienne sont calculées et elles donnent les résultats suivants:

1. La croissance d'épaisseur d'os frontale est continue et assez linéaire de 3 ans jusqu'à l'âge adulte.

2. Fossa cranii anterior présente une forte augmentation de longueur jusqu'à l'âge d'environ 7 ans, et ensuite une augmentation de longueur minime jusqu'à l'âge de puberté.

3. L'augmentation de la longueur externe de basis cranii anterior, de sella à nasion, présente une combinaison des deux types d'augmentation susdits, avec une augmentation de longueur relativement forte jusqu'à l'âge d'environ 7 ans, suivie d'une augmentation assez linéaire jusqu'à l'âge mûr.

4. Basis cranii posterior augmente d'une manière assez linéaire jusqu'à l'âge mûr.

En ce qui concerne la forme de la base du crâne et quelques-unes des structures ayant un rapport avec elle, les résultats suivants paraissent:

5. La forme externe de la base du crâne, mesurée par l'angle *n-s-ba*, de même que la forme interne de la base du crâne, mesurée par l'angle *eth-s-ba*, sont en moyenne presque inchangées depuis l'âge de 3 ans jusqu'à l'âge adulte.

Les fluctuations moins grandes ne se laissent pas apprécier sur l'ensemble considéré.

6. La protrusion de la pointe d'os nasale, mesurée par l'angle *s-n-na*, s'accroît d'environ 16 degrés d'une façon continue de 3 ans jusqu'à l'âge adulte.

7. Comme plan de référence dans la base antérieure du crâne, on a employé la ligne nasion-sella et la ligne ethmoidale-sella (Figure 1). On a essayé d'apprécier la stabilité de cette dernière ligne par rapport à la première pendant la croissance en utilisant la distance perpendiculaire d'ethmoidale à *NSL*. Cette distance est en moyenne assez constante pendant toute la période de croissance depuis 3 ans jusqu'à l'âge adulte. De même la distance perpendiculaire du toit de l'orbite à *NSL* reste presque invariable avec l'âge. Ceci indique que nasion pendant la croissance se déplace d'une manière générale vers l'avant dans le sens longitudinal de fossa cranii anterior. Individuellement, on peut cependant s'attendre à ce que nasion puisse s'élever ou s'abaisser pendant la croissance, se qui est montré par les études corrélatives ci-dessous.

#### Covariations (Tableau 5)

8. Le rapport entre la forme externe et la forme interne de la base du crâne est calculé comme la corrélation entre les angles *n-s-ba* et *eth-s-ba*. Le coefficient de corrélation pour l'ensemble étudié est  $+0.86$ . En gros, la forme externe et la forme interne de la base du crâne se comportent de manière semblable, mais des divergences individuelles relativement grandes peuvent se produire.

9. La question du rapport entre le niveau vertical de nasion et la forme interne de la base du crâne est étudiée. En cas d'une forte courbure de la base interne du crâne, il semble que nasion se déplace vers le haut par rapport à fossa cranii anterior, et vers le bas lors de l'aplatissement de la base interne du crâne. Autrement dit la forme externe de la base du crâne, mesurée par rapport à nasion, masquerait en partie la forme interne de la base du crâne.

10. Il ressort de cette étude que la rotation du haut du visage ainsi que celle du bas du visage est associée plus étroitement à la forme de la base crânienne lorsque *ESL* est employée comme ligne de référence au lieu de *NSL*. Ceci implique que les études corrélatives entre la forme de la base crânienne et la forme du visage devront être basées sur la forme interne de la base du crâne.

## ZUSAMMENFASSUNG

## EXTERNE UND INTERNE SCHÄDELBASIS.

*Wachstum und Association in Formentwicklung*

Ein Vergleich zwischen der externen und der internen Schädelbasisform wurde nach Profilröntgenbildern von 464 dänischen Knaben — aufgeteilt in zwei Altersgruppen: eine von 3—15 Jahren und eine erwachsene Gruppe von 19—25 Jahren — ausgeführt. Die Untersuchung besteht aus zwei Abschnitten. Im ersten Abschnitt wurde die generelle Wachstumstendenz der verschiedenen Dimensionen und Winkel der Schädelbasis analysiert; im zweiten Abschnitt wurde die Association zwischen der äusseren und der inneren Schädelbasisform untersucht.

**Wachstumsveränderungen, (Tab. 1 u. 2. Abb. 2—6)**

Die externe Länge der Basis cranii anterior ist auf den Röntgenfilmen in zwei Komponente geteilt: die Länge der Fossa cranii anterior und die Dicke des Os frontale. Die Dicke des Os frontale wurde für sich gemessen, und die Länge der Fossa cranii anterior wurde indirekt bestimmt, indem die Dicke des Os frontale vom Abstand Nasion—Sella subtrahiert wurde. Die posteriore Schädelbasislänge wurde im Medianplan von Sella bis Basion gemessen. Die Distanzkurven dieser verschiedenen Dimensionen der Schädelbasis wurden berechnet und ergaben folgende Resultate:

1. Das Wachstum des Os frontale ist kontinuierlich und ziemlich gradlinig von 3 Jahren an bis zum erwachsenen Alter.

2. Die Fossa cranii anterior zeigt starkes Längenwachstum bis zum Alter von etwa 7 Jahren, und danach bis zum Pubertätsalter verlängert sie sich nur unbedeutend.

3. Das externe Längenwachstum der Basis cranii von Sella bis Nasion zeigt eine Kombination von beiden obengenannten Wachstumstypen mit einer relativ starken Längensteigerung bis zum Alter von 7 Jahren und danach eine ziemlich gradlinige Steigerung bis zum erwachsenen Alter.

4. Die Basis cranii posterior verlängert sich ziemlich gradlinig bis zum erwachsenen Alter.

In Bezug auf die Schädelbasisform und auf einige der Struk-

turen, die in Relation zu dieser stehen, ergeben sich folgende Resultate:

5. Sowohl die externe Schädelbasisform, gemessen durch den Winkel *n-s-ba*, als auch die interne Schädelbasisform, gemessen durch den Winkel *eth-s-ba* bleibt, im Durchschnitt gesehen, von 3 Jahren an bis zum erwachsenen Alter ziemlich unverändert. Kleinere Fluktuationen lassen sich nach dem vorhandenen Material nicht beurteilen.

6. Der Os nasale zeigt während des Wachstums, gemessen durch den Winkel *s-n-na*, eine kontinuierlich zunehmende Protrusion von ca. 16 Grad von 3 Jahren an bis zum erwachsenen Alter.

7. Als Referenzplan in der anterioren Schädelbasis wurde sowohl die Linie Nasion—Sella, als auch die Linie Ethmoidale—Sella (Abb. 1) angewandt. Die Stabilität der ersten im Verhältnis zu der anderen während des Wachstums wurde versuchsweise beurteilt, indem der rechtwinklige Abstand von Ethmoidale bis *NSL* gezogen wurde. Dieser Abstand ist durchschnittlich während der ganzen Wachstumperiode von 3 Jahren an bis zum erwachsenen Alter nahezu konstant. Ebenso bleibt der rechtwinklige Abstand vom Augenhöhlendach bis zur *NSL* fast unverändert mit dem Alter. Dieses deutet darauf hin, dass sich der Nasion — generell gesehen — während des Wachstums nach vorn in die Längenrichtung der Fossa cranii anterior verschiebt. Individuell kann man aber doch erwarten, dass sich der Nasion während des Wachstums sowohl hebt, als auch senkt. Dieses wird unten bei der korrelativen Untersuchung gezeigt.

#### Kovariation (Tab. 5)

8. Die Association zwischen der externen und der internen Schädelbasisform wurde durch Korrelation zwischen den Winkeln *n-s-ba* und *eth-s-ba* berechnet. Der Korrelationskoeffizient für das ganze Material ist + 0,86. Im allgemeinen verändern sich die äussere und die innere Schädelbasisform in Übereinstimmung zu einander, aber individuell können relativ grosse Abweichungen vorkommen.

9. Die Frage, wie das vertikale Niveau des Nasion mit der internen Schädelbasisform associiert ist, wurde behandelt. Es zeigt

sich bei starker Beugung der internen Schädelbasis, dass sich der Nasion nach oben in Relation zu Fossa cranii anterior verschiebt und bei Abflachung der internen Schädelbasis nach unten. Daraus folgert man, dass die externe Schädelbasisform — bis zum Nasion gemessen — die interne Schädelbasis zum Teil verdeckt.

10. Es zeigt sich ferner, dass die Rotation sowohl des Oberals auch des Untergesichtes grössere Association mit der Schädelbasisform hat, wenn *ESL* anstatt *NSL* als Referenzlinie angewandt wird. Deshalb müsste bei korrelativen Studien zwischen Schädelbasisform und Gesichtsform die interne Schädelbasisform als Grundlage dienen.

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