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TIME OF CLOSURE OF THE SPHENO-OCCIPITAL SYNCHONDROSIS DETERMINED ON DRY SKULLS

A RADIOGRAPHIC CRANIOMETRIC STUDY

by

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INTRODUCTION

Our knowledge of the precise time of closure of the spheno-occipital synchondrosis is sparse. In profile radiographs of living subjects it is not possible with certainty to determine whether the synchondrosis is open, or partially or completely closed. During recent years, tomography has therefore been used as a method of investigation in this field. In a study of 47 individuals of both sexes whose ages range from 5 to 26 years, *Irwin* (1960) found, by means of a single tomographic section in the mid-sagittal plane, that in some of the children studied the spheno-occipital synchondrosis closed as early as at the age of 11, and that closure had occured in the majority of cases at the age of 13. On the basis of a tomographic study of 398 subjects aged from 6 to 18 years, *Powel & Brodie* (1964) claimed that closure of the synchondrosis usually occurs at the age of 13 in boys and at 12 in girls. On dry skulls it is easy to ascertain if the synchondrosis is closed, but here it is very difficult to determine the exact chronological age. By inspection of 707 anthropoid skulls, *Krogman* (1930) found that closure occurred in the period between the eruption of the second and third molars. *Ford* (1958) investigated 66 human skulls and found that the spheno-occipital synchondrosis closed at the time of the eruption of the third molar. It is

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thus seen that the results obtained in these studied varied with the material and methods used.

The growth of the cranial base and the contribution of the spheno-occipital synchondrosis to this process have been the subject of various investigations.

Histological studies of the synchondrosis were made by *Orban* (1957), *Lager* (1958), *Baume* (1957, 1961) and *Sicher* (1962), who all described it as an important growth centre.

In profile radiographs of living subjects, *Brodie* (1941) performed a longitudinal study of the growth of the cranial base from the age of 3 months to 8 years. He expressed the view that although the cranial base increased in length throughout the entire period under investigation, the contribution of the synchondrosis to it is of only limited importance after the age of 18 months. In a longitudinal study of the growth of the cranial base in 12 girls and 18 boys covering the period from 3 to 18 years, *Brodie Jr.* (1955) claimed that the size of the individual components anterior to the foramen magnum increased proportionally, so that their interrelationship remained constant during childhood and adolescence.

The localization of the synchondrosis renders it difficult, particularly during the period when closure occurs, to study the area by means of profile radiographs in living subjects. In the present study an attempt was made to determine the time of closure of the spheno-occipital synchondrosis in relation to the dental development by direct inspection of dry skulls. At the same time, the sizes of the individual components of the cranial base were determined on profile radiographs of skulls in various age groups in order to assess the growth of the basal synchondrosis.

MATERIAL AND METHODS

The material studied consisted of 132 skulls from India representing different age groups (*Melsen*, 1967). As it was not possible accurately to determine the chronological age, the skulls were classified according to the stages of the dental development defined as follows (*Björk, Krebs & Solow*, 1964):

DS	02	Deciduous teeth fully erupted
DS	1	Permanent incisors erupting
DS	2	Permanent incisors fully erupted
DS	3	Canines or premolars erupting
DS	4	Canines and premolars fully erupted
DS	M2	Second molars fully erupted
DS	M3	Third molars fully erupted

The material studied ranged from fully erupted deciduous teeth to fully developed permanent dentition. The combination of DS 4 and DS M2 is designated DS 4-M2. In view of the definition, each of the two stages DS 1 and DS 2 represented a very small group; they were therefore combined and designated as DS 1—2. The group DS M3 consisting of skulls with fully erupted third molars represented the adult individual. A few skulls which according to skeletal age belonged to the group M3, were classified from the stage of dentition as DS M2 because of aplasia or retention of the third molars.

Method of Investigation

The closure of the synchondrosis was studied by direct inspection of the skulls. In order to facilitate accurate localization of the structures on the profile radiographs, the course of the clivus, the anterior margin of the foramen magnum and the spheno-occipital synchondrosis were marked with 0.5 mm lead wire. Whenever possible, lead wire was also placed on both the anterior and posterior borders of the synchondrosis. In addition, the reference point hormion was marked with a gramophone needle.

The profile radiographs were taken with the skulls placed in a cephalostat. The film-focus distance was 190 cm, and the distance from the mid-sagittal plane to the film was 10 cm, resulting in an average magnification of 5.6 %. In the calculations, no correction was made for this magnification. SINO-films were used, and the exposures were made without intensifying screen to ensure the best possible quality. Five DS 4-M2 skulls which in profile radiographs seemed to reveal incipient closure were selected in order to check the accurary of tomography. Tomographic sections, 2.5 mm apart, were made of the five skulls twice. The two sets of exposures were then compared individually. In two of the five skulls, the estimation of the closure of the synchondrosis differed in the two sets. This difference must be ascribed to uncertainty in the localization of the individual tomographic sections, i.e. tomography does not provide unquestionable information as to the state of the synchondrosis.

The reference points employed were as follows (see Figs. 1 and 2):

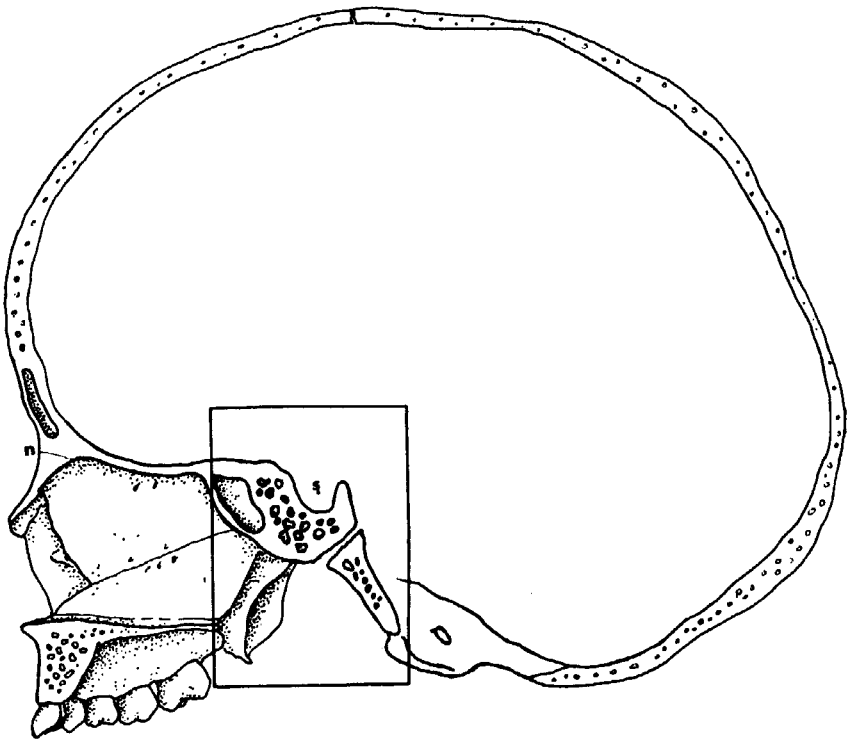
s — Sella. The centre of the sella turcica.

s' — Sella'. The deepest point of the floor of the sella turcica.

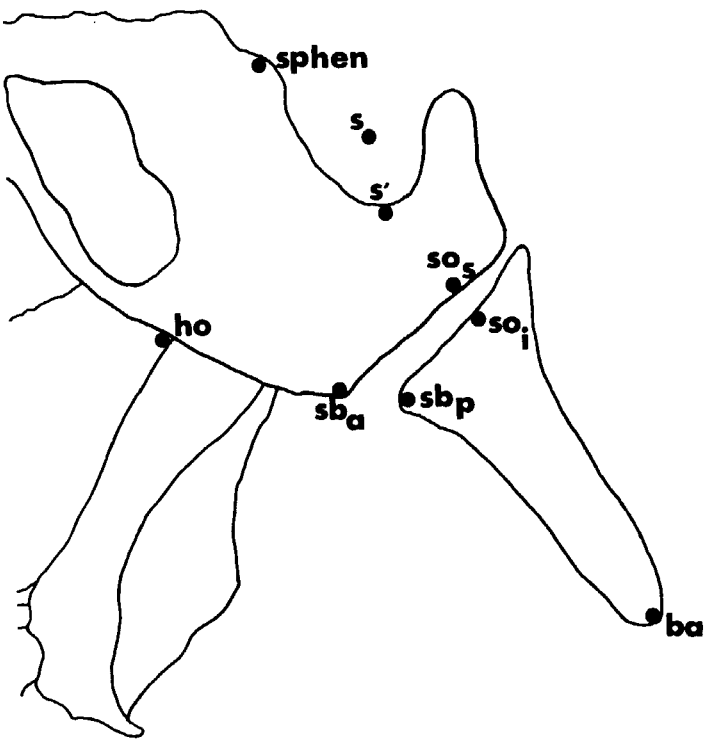
n — Nasion. The most anterior point of the nasofrontal suture.

ba — Basion. The extreme postero-inferior point of the clivus.

ho — Hormion. The extreme dorsal point of contact of the vomer with the sphenoid body in the mid-sagittal plane between the alae of the vomer.



Figs. 1 and 2. Reference points employed on profile radiographs.



sphen — Sphenoidal point. The uppermost point of the tuberculum sellae.

sb_a — Sphenobasion anterior. The most inferior point of the posterior surface of the sphenoid body.

sb_p — Sphenobasion posterior. The most inferior point of the anterior surface of the basilar part of the occipital bone.

so_s — Synchondrosis spheno-occipital superior. The point of intersection between the s-ba line and the posterior surface of the sphenoid body.

so_i — Synchondrosis spheno-occipitalis inferior. The point of intersection between the s-ba line and the anterior surface of the basilar part of the occipital bone.

The following measurements were made:

Linear measurements

1.	n-s	9.	s-so_s	17.	ho-ba
2.	n-ba	10.	s-ba	18.	sphen-sb_a
3.	n-ho	11.	s'-sb_a	19.	sphen-sb_p
4.	n-sb_a	12.	s'-sb_p	20.	so_i-ba
5.	n-sb_p	13.	ho-sb_a	21.	sphen-s
6.	s-ho	14.	ho-sb_p	22.	s-s'
7.	s-sb_a	15.	sb_a-ba	23.	sphen-s'
8.	s-sb_p	16.	sb_p-ba		

Angular measurements

1.	n-s-ba	2.	n-s-ho

The measurements were made direct on the films as described by *Björk & Solow* (1964). The distances were measured to the nearest 0.1 mm and the angles to the nearest half degree.

Error of the Method

The error of the method was checked by duplicate measurements on 10 skulls from various age groups. After renewed marking of the skulls, repeat profile radiographs were taken, on which a new set of measurements were made. Student's t-test did not reveal any systematic error. The magnitude of the random error, s(i), is given in Table I.

A comparison of s(i) with similar values obtained in cephalometric studies of dry skulls (*Lysell & Philipsen*, 1958; *Bergland*, 1963) showed that the random error was usually small, probably due to the marking of the reference points which were difficult to define. However, for the angular measurement n-s-ba, s(i) was great, viz. 1.6°, presumably because it is difficult to locate

Table I.

The error of the method, as checked by duplicate measurements on 10 skulls

n-s	= 0.77 mm	s-so_s	= 0.29 mm	sb_p-ba	= 0.29 mm
n-ba	= 0.19 mm	s-ba	= 0.34 mm	ho-ba	= 0.30 mm
n-ho	= 0.18 mm	s-s'	= 0.31 mm	sphen-sb_a	= 0.24 mm
n-sb_a	= 0.21 mm	s'-sb_a	= 0.42 mm	sphen-sb_p	= 0.56 mm
n-sb_p	= 0.32 mm	s'-sb_p	= 0.39 mm	sphen-s'	= 0.39 mm
s-ho	= 0.27 mm	ho-sb_a	= 0.37 mm	sphen-s	= 0.36 mm
s-sb_a	= 0.32 mm	ho-sb_p	= 0.28 mm	so_i-ba	= 0.43 mm
s-sb_p	= 0.31 mm	sba-b_a	= p.41 mm	n-s-ba	= 1.55°
				n-s-ho	= 1.24°

$$s(i) = \sqrt{\frac{\Sigma\,(x^1 - x^2)^2}{2\,N}}$$

the basion on radiographs of children's skulls, where the anterior margin of the foramen magnum is most frequently obtusely rounded. The large random error for the angle n-s-ho may be due to difficulties in marking ho.

RESULTS

Distributions

It appears from Tables II—V that only a few sets of variables showed deviation from the normal distribution at the 1 % level. At DS 1—2 and DS 3, the distributions revealed a distinct tendency to platykurtosis, presumably because the skulls at these stages differed in skeletal age and could not be grouped according to sex. The variation coefficients for some of the linear dimensions, viz. ho-sb_p and ho-sb_a, were very great. However, this is only what might be expected in view of the small mean values of these measurements (*Pearson & Woo*, 1935; *Lindegaard & Sonesson*, 1952; *Solow*, 1966).

Dimensional Changes

With a few exceptions, the mean values of the linear dimensions increased up to DS 4-M2 (Table VII and Fig. 3). The exceptions were seen in cases in which the anterior reference point was ho. According to *Takagy* (1964) and *Melsen* (1967), this point moves backwards in relation to the sphenoid body, and, in agreement with this, the distances from ho to the inferior border of the synchondrosis and to the basion are reduced. After DS 4-M2, the distances from the sellar region to n, ba and to the proximal surface of

Table II.
Statistical description of the distributions
Dental stage 02 (deciduous teeth fully erupted), 48 skulls

variable	range min	range max	$\bar{x}$	s	$s(\bar{x})$	V	skewness b1	kurtosis b2	a
n-s	51.4	66.9	59.31	3.07	.443	5,17	.158	3.08	.7778
n-ba	75.7	94.6	84.65	3.93	.613	4.64	—.198	3.13	.8052
n-ho	48.9	66.6	57.07	3.50	.561	6.30	.203	3.41	.7953
n-sb_a	59.4	73.4	64.81	2.99	.468	4.62	.200	3.14	.8244
n-sb_p	61.0	74.9	67.04	3.04	.475	4.54	.109	2.74	.8330
s-ho	14.8	20.4	18.16	1.26	.220	6.95	—.308	3.06	.7907
s-sb_a	14.3	19.9	16.56	1.23	.189	7.40	.288	3.18	.7570
s-sb_p	15.4	21.5	17.77	1.36	.213	7.67	.697	3.26	.8168
s-so_s	9.5	14.5	11.65	.98	.150	8.44	.208	3.59	.7733
s-ba	27.3	37.2	32.11	2,47	.464	7.69	.048	2.41	.7988
s-s'	2.1	5.1	3.18	.61	.088	19.15	.817	4.10	.7459*
s'-sb_a	11.2	17.3	13.54	1.23	.192	9.09	.604	3.70	.7718
s'-sb_p	12.0	18.4	14.76	1.36	.213	9.24	.601	3.51	.7779
ho-sb_a	5.6	12.2	8.88	1.69	.264	19.03	—.017	2.12	.8657*
ho-sb_p	8.0	13.8	11.56	1.55	.239	13.40	—.430	2.32	.8657*
sb_a-ba	15.6	23.8	20.01	2.01	.314	10.05	—.339	2.47	.8021
sb_p-ba	14.0	21.7	18.37	1.95	.304	10.61	—.364	2.59	.7710
ho-ba	23.5	32.2	27.97	1.82	.285	6.52	.179	3.20	.7840
sphen-sb_a	16.2	26.3	19.09	1.95	.301	10.95	1.347	6.28	.7125**
sphen-sb_p	18.4	27.8	21.13	1.77	.273	8.38	1.458	6.32	.7391*
sphen-s'	4.8	12.8	6.81	1.34	.193	19.64	1.971	9.87	.6697
sphen-s'	3.0	7.7	4.36	.76	.110	17.45	1.559	9.02	.7769
so_i-ba	15.4	23.2	19.4	1.91	.291	9.96	—.060	2.39	.8096
n-s-ba	123.5	145.0	134.89	4.97	.733		—.206	2.75	.8053
n-s-ho	64.0	87.0	76.77	5.32	.830		.179	2.63	.8282

the synchondrosis continued to increase, whereas no changes in the distances from the sella turcica to the distal surface of the synchondral cartilage could be demonstrated.

Stability of the Sella Point

As the reference point s was used in most of the measurements of the synchondrosis, the stability of this point was studied by measurements in the sellar region. It was found that the mean distance from the tuberculum sellae (sphen) to the sella point increased by 1.6 mm from DS 02 to DS M3, which corresponds to an increase in the longest diameter by 3.2 mm. At

Table III.

Statistical description of the distributions
Dental stage 1—2 (incisors erupting or fully erupted), 20 skulls

variable	range min	range max	$\bar{x}$	s	$s(\bar{x})$	V	skewness b1	kurtosis b2	a
n-s	58.8	68.4	63.27	2.42	.541	3.82	.242	2.63	.8080
n-ba	84.0	95.7	90.77	3.65	.884	4.02	—.470	2.17	.8214
n-ho	57.5	66.9	62.16	3.15	.763	5.06	—.041	1.79	.8527
n-sb_a	64.5	73.4	69.34	2.85	.692	4.14	—.149	1.68	.9012**
n-sb_q	66.5	75.5	71.20	2.66	.644	3.73	—.246	2.04	.8735
s-ho	18.8	23.1	21.21	1.33	.305	6.28	—.269	1.98	.8571
s-sb_a	16.3	21.1	18.75	1.56	.378	.832	—.111	1.74	.8763
s-sb_p	17.6	21.8	19.62	1.23	.299	6.28	.051	2.14	.7950
s-so_s	11.0	15.1	13.21	.97	.234	7.31	—.231	3.13	.7805
s-ba	32.1	40.0	36.37	2.10	.470	5.77	—.497	2.70	.7625
s-s'	2.5	4.3	3.35	.52	.116	15.45	.313	2.03	.7765
s'-sb_a	13.5	17.9	15.45	1.31	.318	8.50	.205	1.95	.8611
s'-sb_q	14.5	18.3	16.26	1.13	.273	6.92	.222	1.95	.8699
ho-sb_a	6.4	10.8	8.86	1.25	.302	14.07	—.390	2.38	.8046
ho-sb_p	9.0	13.2	10.84	1.28	.310	11.81	.296	2.08	.8452
sb_a-ba	20.0	24.4	21.68	1.33	.323	6.14	.439	2.11	.8653
sb_p-ba	18.3	23.1	20.74	1.33	.323	6.41	.187	2.56	.8330
ho-ba	26.4	31.3	28.77	1.27	.308	4.41	.023	2.56	.8200
sphen-sb_a	18.5	25.8	21.69	1.68	.409	7.77	.461	3.57	.7662
sphen-sb_p	20.5	26.9	23.48	1.61	.389	6.84	.847	3.07	.7546
sphen-s'	5.7	11.2	7.57	1.29	.288	17.04	.903	4.24	.7553
sphen-s	3.4	5.8	4.76	.71	.158	14.86	—.130	1.84	.8643
so_i-ba	19.1	24.1	21.89	1.41	.341	6.42	.298	1.94	.8674
n-s-ba	124.5	138.2	132.17	3.50	.782		—.301	2.85	.7882
n-s-ho	71.0	86.5	79.66	4.15	1.039		—.340	2.57	.8265

the same time, the mean distance from the tuberculum sellae to the deepest point of the floor of the sella (s') increased by 2.3 mm. Finally, the distance s-s' increased by 1.0 mm.

These findings are suggestive of eccentric growth of the sella turcica resulting in a downward and backward shift of the sella point in relation to the tuberculum sellae.

Growth of the Synchondrosis

The growth of the synchondrosis was assessed by measurements of the increase in the distance from the sella turcica to the distal surface of the syn-

Table IV.

Statistical description of the distributions
Dental stage 3 (canines and premolars erupting), 14 skulls

variable	range min	range max	x	s	s(x)	skewness V	skewness b1	kurtosis b2	a	D
n-s	56.5	70.5	65.39	3.88	1.038	5.94	—.622	2.86	.8288	.0930
n-ba	81.2	103.9	95.44	6.66	2.007	6.97	—.800	2.93	.8182	.1054
n-ho	54.7	70.9	65.36	4.52	1.361	6.91	—.008	3.86	.7694	.0992
n-sba	62.6	78.6	72.23	4.75	1.431	6.57	—.552	2.57	.8100	.0996
n-sbp	63.8	79.6	73.81	4.70	1.419	6.37	—.716	2.82	.8080	.0996
s-ho	18.0	22.6	21.03	1.59	.481	7.58	—.626	2.18	.8482	.1864
s-sba	17.9	23.3	19.39	1.48	.445	7.61	1.833	5.87	.7034	.2417
s-sbp	19.4	21.8	20.50	1.03	.311	5.01	.239	.132	.9153	.2187
s-so_s	12.5	15.1	13.68	.94	.284	6.88	.190	1.65	.8835	.1772
s-ba	33.3	47.7	39.62	4.61	1.231	11.63	.116	1.85	.8857	.1700
s-s'	2.8	4.6	3.64	.61	.162	16.63	.428	1.81	.8549	.1680
s'-sba	14.1	19.3	16.13	1.41	.425	8.74	.761	3.70	.7690	.1174
s'-sbp	15.8	18.9	17.15	1.07	.323	6.24	.534	1.90	.8821	.2128
ho-sba	5.3	9.9	7.63	1.79	.540	23.48	—.157	1.34	.9481**	.1816
ho-sbp	7.4	12.1	9.20	1.65	.497	17.90	.417	1.89	.8820	.2515
sba-ba	19.9	27.3	23.30	3.69	1.113	15.84	—.422	1.70	.9173*	.1174
sbp-ba	18.6	26.8	22.01	3.01	.906	13.06	—.195	1.40	.8466	.1738
ho-ba	24.8	34.9	30.04	3.46	1.044	11.53	.072	1.84	.8350	.1358
sphen-sb	19.7	25.8	22.65	1.66	.501	7.34	.014	2.82	.7660	.1329
sphen-sb	22.1	26.5	24.22	1.24	.374	5.12	.021	2.61	.7747	.0893
sphen-s'	6.0	10.4	7.74	1.29	.346	16.71	.669	2.49	.8097	.2323
sphen-s	4.0	6.6	4.98	.67	.178	13.66	.799	3.76	.7292	.1976
soi-ba	19.4	28.9	23.80	3.31	.998	13.91	.117	1.65	.8851	.1521
n-s-ba	120.0	144.5	131.12	7.19	1.923		.129	2.36	.8043	.2140
n-s-ho	76.5	90.0	83.82	4.80	1.448		—.181	1.67	.8970	.1500

chondrosis (s-sb_p, s'-sb_p, sphen-sb_p and s-so_i). These dimensions continued to increase up to DS 4-M2. The position of sb_p on the junction of the distal surface of the synchondrosis and the inferior aspect of the occipital part of the clivus is influenced not only by the growth of the synchondrosis, but also by an unknown bone apposition on the inferior aspect of the clivus. The distance from the sella point (s) to a point in the middle of the distal surface of the synchondrosis (so_i) increased by 2.8 mm from DS 02 up to the closure of the synchondrosis. This increase is equal to the growth of the synchondral cartilage minus the ossification of its distal surface and the shift of the sella point, and must be taken as evidence of continued growth of the synchondrosis up to DS 4-M2.

Table V.

Statistical description of the distributions
Dental stage 4-M2 (canines, premolars and second molars fully erupted), 30 skulls

variable	range min	range max	$\bar{x}$	s	$s(\bar{x})$	V	skewness b1	kurtosis b2	a
n-s	59.5	73.5	65.88	4.10	.748	6.22	.118	1.96	.8639*
n-ba	86.5	113.3	97.20	5.60	1.040	5.76	.748*	3.93	.7890
n-ho	59.5	72.6	66.41	3.87	.719	5.83	—.116	1.98	.8483
n-sb_a	63.0	83.6	72.73	5.08	.943	6.98	.044	2.61	.8092
n-sb_p	67.7	84.5	74.39	4.42	.821	5.94	.381	2.76	.7741
s-ho	19.1	24.4	21.68	1.49	.292	6.86	.143	2.17	.8155
s-sb_a	17.4	25.0	20.83	1.62	.301	7.79	.161	3.30	.7694
s-sb_p	18.4	24.8	21.47	1.57	.292	7.32	.002	2.42	.8124
s-so_s	11.4	19.8	14.54	1.89	.352	13.02	.887	3.71	.7529
s-ba	30.3	52.5	39.97	3.84	.701	9.61	.654	5.81	.7313
s-s'	2.5	5.1	3.63	.63	.114	17.27	.598	3.09	.7659
s'-sb_a	14.0	21.8	17.53	1.72	.320	9.83	—.062	3.20	.7484
s'-sb_p	14.1	22.0	18.00	1.68	.313	9.36	—.110	3.18	.7838
ho-sb_a	4.8	11.6	7.72	2.05	.380	26.53	.336	2.13	.8571
ho-sb_p	5.3	14.0	9.09	2.37	.440	26.05	.242	2.28	.8234
sb_a-ba	20.8	28.4	24.21	1.79	.332	7.38	.161	2.78	.7776
sb_p-ba	20.0	28.3	22.89	1.92	.357	8.40	.537	3.35	.8039
ho-ba	27.0	38.6	30.81	2.63	.488	8.53	.863*	3.74	.7992
sphen-sb_a	20.6	29.8	24.19	2.15	.398	8.87	.851*	3.26	.7673
sphen-sb_p	22.8	29.8	25.34	1.94	.361	7.66	.463	2.42	.8105
sphen-s'	5.7	12.1	8.03	1.57	.287	19.53	.927	3.41	.7706
sphen-s	4.0	6.7	5.15	.74	.135	14.33	.549	2.45	.8172
so_i-ba	21.0	28.6	24.20	1.89	.350	7.79	.418	3.52	8295.
n-s-ba	120.0	155.0	133.37	6.70	1.224		.701	5.21	.7183*
n-s-ho	76.0	94.5	83.90	4.76	.883		.360	2.77	.7922

The ossification of the proximal surface of the cartilage can be assessed by the increase in the distances from the sellar region to the proximal surface of the synchondrosis (s'-sb_s, sphen-sb_s and s-so_s). Owing to the downward and backward shift of the sella point, the increase of 2.9 mm in the distance from s to the proximal surface (s-so_s) is actually less than that due to the ossification of the proximal surface, whereas the increase of 6.1 mm in the distance between the tuberculum sellae and the most inferior point of the proximal surface of the cartilage is greater than if it was only an expression of the ossification occurring along the proximal surface of the cartilage, as it is influenced both by the external apposition and by any apposition of the tuberculum sellae, i.e. that, as a consequence of ossification along

Table VI.
Statistical description of the distributions
Dental stage M3 (third molars, fully erupted), 20 skulls

variable	range min	range max	$\bar{x}$	s	$s(\bar{x})$	V	skewness b1	kurtosis b2	kurtosis a
n-s	59.6	72.4	66.38	3.46	.774	5.22	.075	2.22	.8517
n-ba	93.6	106.1	100.65	3.53	.790	3.51	—.262	2.02	.8636
n-ho	62.1	77.1	69.84	3.67	.821	5.26	—.464	3.23	.7460
n-sba	70.1	80.4	75.52	.298	.667	3.95	—.092	2.13	.8348
n-sbp	70.1	80.4	75.52	2.98	.667	3.95	—.092	2.13	.8348
s-ho	18.5	25.5	21.84	1.90	.425	8.71	.163	2.45	.8148
s-sba	18.6	24.9	21.71	1.86	.427	8.57	.030	2.10	.8501
s-sbp	18.6	24.9	21.71	1.86	.427	8.57	.030	2.10	.8501
$s\text{-}so_s$									
s-ba	37.0	46.8	42.27	3.03	.678	7.17	—.158	2.00	.8303
s-s'	2.7	5.5	4.16	.72	.160	17.23	.041	2.81	.7934
s'-sba	15.3	23.3	17.98	2.19	.502	12.17	.635	2.81	.8200
s'-sbp	15.3	23.3	17.98	2.19	.502	12.17	.635	2.81	.8200
ho-sba	3.0	12.5	6.10	2.15	.482	35.34	1.119	5.17	.7034*
ho-sbp	3.0	12.5	6.10	2.15	.482	35.34	1.119	5.17	.7034*
$sb_a\text{-}ba$	21.4	29.4	25.21	2.10	.470	8.30	—.232	2.54	.8160
$sb_p\text{-}ba$	21.4	29.4	25.21	2.10	.470	8.30	—.232	2.54	.8160
ho-ba	28.0	36.9	32.92	2.23	.500	7.23	.769	3.50	.8212
sphen-sba	21.4	29.1	26.07	1.87	.418	7.18	—.732	3.26	.7926
sphen-sp	21.4	29.1	26.07	1.87	.418	7.18	—.732	3.26	.7926
sphen-s'	6.4	11.8	9.07	1.40	.312	51.39	.171	2.29	.8171
sphen-s	5.0	7.0	6.00	.60	.135	10.07	.020	1.95	.8245
$so_i\text{-}ba$									
n-s-ba	126.5	139.0	133.27	3.72	.832		—.096	1.84	.8814*
n-s-ho	76.5	95.5	88.70	5.01	1.120		—.941	3.68	.7292*

this surface, the distance from s to the proximal surface of the cartilage is increased by more than 2.9 mm and by less than 6.1 mm.

The present investigation did not provide exact information as to the ossification along the distal surface of the cartilage. The increase in the distance from this surface to the basion was 5.1 mm, but this increase may be partially attributed to appositional growth in the basion region.

Closure of the Spheno-occipital Synchondrosis

Direct inspection of the skulls revealed that the synchondrosis was open in all cases in the groups DS 02, DS 1—2 and DS 3 and completely closed in

Table VII.

Means of the variables at the 5 different stages
Equality of the means has been tested by means of an analysis of variance for each variable (F)

variable	DS 02	DS 1-2	DS 3	DS4-M2	DS M3	F^4_{127}
n-s	59.31	63.27	65.39	65.88	66.38	26.27**
n-ba	84.65	90.77	95.44	97.20	100.65	54.88**
n-ho	57.07	62.16	65.36	66.41	69.84	46.94**
n-sba	84.81	69.34	72.23	72.73	75.62	37.21**
n-sbp	67.04	71.20	73.81	74.39	75.52	28.60**
s-ho	18.16	21.21	21.03	21.68	21.84	2.80*
s-sba	16.56	18.75	19.39	20.83	21.71	53.37**
s-sbp	17.77	19.62	20.50	21.47	21.71	37.71**
s-sos	11.65	13.21	13.68	14.54		51.53**
s-ba	32.11	36.37	39.62	39.97	42.27	79.59**
s-s'	3.18	3.35	3.64	3.63	4.16	8,79**
s'-sba	13.54	15.45	16.13	17.53	17.98	39.01**
s'-sbp	14.76	16.26	17.15	18.00	17.98	23.75**
ho-sba	8.88	8.86	7.63	7.72	6.10	9.01**
ho-sbp	11.56	10.84	9.20	9.09	6.10	30.87**
sba-ba	20.01	21.68	23.30	24.21	25.21	27.62**
sbp-ba	18.37	20.74	22.01	22.89	25.21	47.22**
ho-ba	27.97	28.77	30.04	30.81	30.92	9.87**
sphen-sba	19.09	21.69	22.65	24.19	26.07	55.51**
sphen-sbp	21.13	23.48	24.22	25.34	26.07	37.17**
sphen-s'	6.81	7.57	7.74	8.03	9.07	9.63**
sphen-s	4.36	4.76	4.98	5.15	6.00	11.14**
soi-ba	14.19	21.89	23.80	24.20		43.83**
n-s-ba	134.89	132.17	131.12	133.37	133.27	1.24
n-s-ho	76.77	79.66	83.82	83.90	88.70	23.29**

all cases in group DS M3. Among the 30 skulls classified as DS 4-M2, partial closure was seen in three and complete closure in three. In the three skulls with partial closure, this comprised only the upper part of the synchondrosis, and in two of them the third molars were partially erupted. As far as closed skulls were concerned, the classification according to dental stage was somewhat uncertain, as profile radiographs revealed aplasia of the third molars in two of them, and partial impaction of the third molars in the third, in which the root development was almost complete although only part of the occlusal surfaces were visible, and all three skulls showed distinct attrition of the second molars.

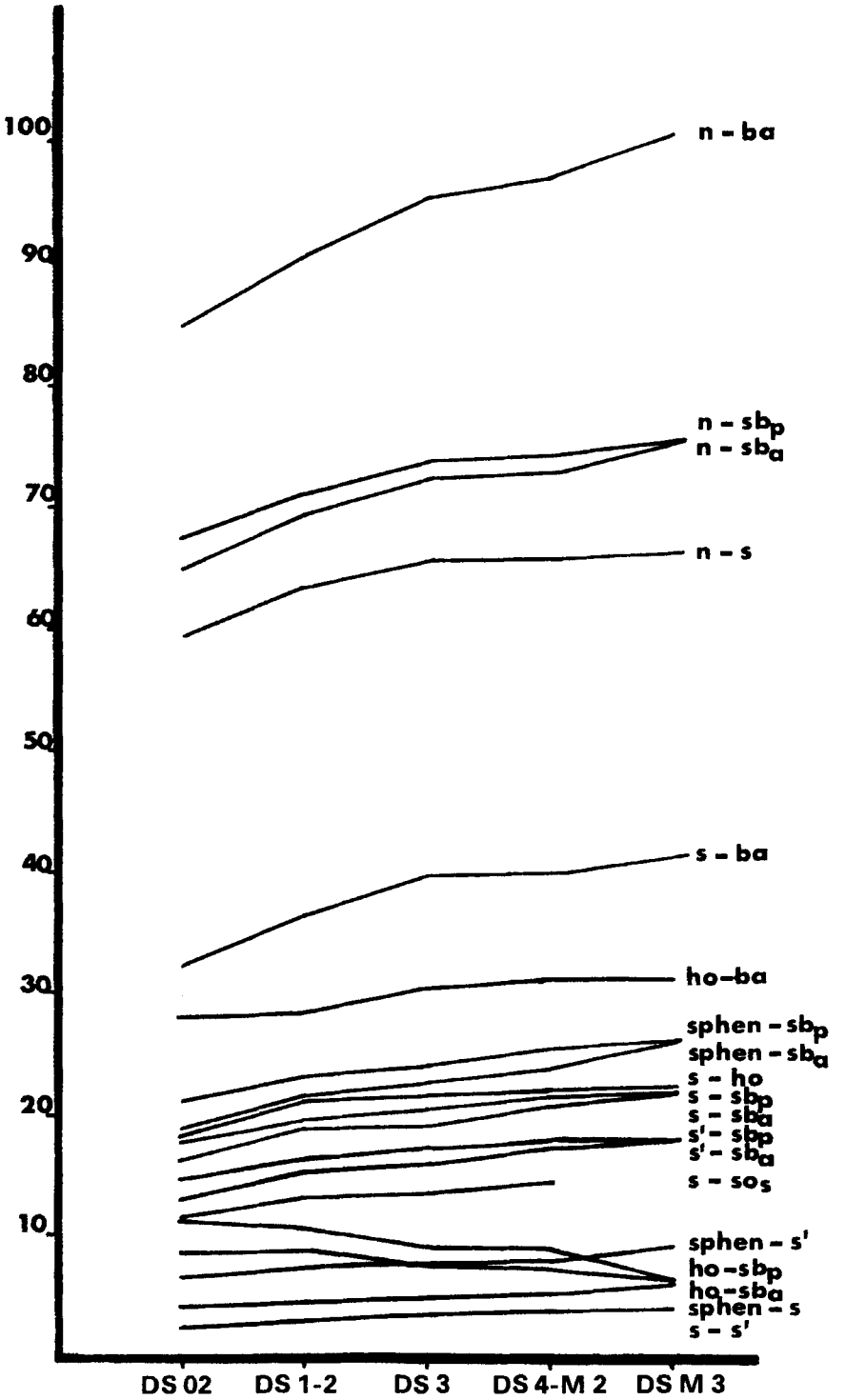


Fig. 3. Growth curves for linear dimensions.

Judging from these observations, incipient closure of the synchondrosis must be assumed to occur at some time between DS 4-M2 and DS 4-M3, i.e. after complete eruption of all second molars.

DISCUSSION

The results of the present investigation as to the time of closure of the spheno-occipital synchondrosis are in good agreement with those obtained in similar studies of cranial material (*Ford*, 1958). On the other hand, investigators employing tomographic methods have reported that closure occured at an earlier stage, viz. at 11 years in boys and girls (*Irwin*, 1958), and at 12 years in girls and 13 years in boys (*Powel & Brodie*, 1964). In addition to the uncertainty with which tomographic methods are beset, the divergent results may be due to racial differences in the material studied.

Based on the measurements reported here, an exact evaluation of the growth of the synchondrosis is not possible because the investigation was cross-sectional in nature, and the results thus were limited to information concerning increase in the mean values for dimensions in the various age groups.

The measurements revealed that the reference point *sella*, on an average, moved 2 mm downwards and backwards in relation to the tuberculum sellae. Such a downward and backward shift of the sella point referable to eccentric growth of the sella turcica was demonstrated in subjects studied longitudinally by *Björk* (1964, 1965). Changes in the size of the pituitary gland during childhood were described by *Peter* (1927), who collected measurements of the pituitary in children of various age groups. He found that during the period from birth to the age of 14 years the gland increased about 2 mm in height and about 6 mm in length.

The growth of the synchondral cartilage adds to the distance from the reference point sella to the distal surface of the cartilage, whereas ossification of this surface and the backward shift of the sella point tend to reduce this distance. Accordingly, as long as the distance increases, the growth of the cartilage must outdo the influence of the two factors just mentioned. Such increase in the distance were observed in the present investigation in the stages up to and including DS 4-M2. Growth of the spheno-occipital synchondrosis throughout this period was questioned by *Brodie* (1941, 1953) and by *Powel* and *Brodie* (1964). Differences in the evaluation of the shift of the sella point during childhood may provide a partial explanation of the divergent opinions as to the growth of the basal synchondrosis. Thus, *Brodie*

(1953) and *Powel* and *Brodie* (1964) assumed that the increase in the distance from the sella point to the spheno-occipital synchondrosis was due to a forward shift of the sella point, and consequently they did not attach any particular importance to the synchondrosis as a centre of growth. *Bodie Jr.* (1955) disregarded shift of the sella point in his calculations, and found that the proportion which the sphenoid body constitutes of the cranial base was constant. Hence, he assumed that the synchondrosis contributed to the increase in size throughout childhood and adolescence.

Histological studies of human material from various age groups are desirable in order definitely to clarify how long growth of the spheno-occipital synchondrosis continues.

SUMMARY

The purpose of the investigation reported here was twofold:
1) to determine the time of the first osseous closure of the spheno-occipital synchondrosis in relation to various stages of dental development, and
2) to describe growth of the individual mid-sagittal structures of the cranial base anterior to the foramen magnum.

The material studied consisted of 132 skulls from India which were classified according to the dental development as defined by *Björk, Krebs* and *Solow* (1964). When unquestionable localization was not possible in profile radiographs, the structures and reference points were marked on the skulls. Linear and angular measurements were made on profile radiographs taken under standardized conditions.

On the basis of direct inspection of the skulls, it was found that closure of the spheno-occipital synchondrosis occured after the eruption of all canines, premolars and second molars. Since tomographs showed only poor agreement with the results obtained by direct observation, the tomographic method must be regarded as fairly unreliable.

Measurements of changes in the dimensions of the structures in the sellar region showed that the sella point, on an average, shifted 2 mm downwards and backwards in relation to the tuberculum sellae during the period between complete eruption of primary and secondary dentitions. In spite of the downward and backward shift of the sella point, the distance from the sella point to the distal surface of the synchondral cartilage continued to increase until the canines, premolars and second molars were fully erupted. This observation was interpreted as evidence of active growth of the synchondral cartilage up to this stage of development.

RÉSUMÉ

CHRONOLOGIE DE LA FERMETURE DE LA SYNCHONDROSE SPHÉNO-OCCIPITALE
DÉTERMINATIONS SUR CRÂNES SECS
ETUDE CRÂNIOMÉTRIQUE RADIOGRAPHIQUE

L'étude présentée ici avait un double but:
1) déterminer l'époque de la première soudure osseuse de la synchondrose sphéno-occipitale par rapport aux différents stades du développement dentaire, et
2) décrire la croissance des différentes structures sagittales médianes de la base du crâne en avant du trou occipital.

Le matériel étudié consistait en 132 crânes provenant d'Inde et classés d'après le développement dentaire suivant les indications de *Björk, Krebs* et *Solow* (1964). Lorsque la localisation sur téléradiographies de profil ne pouvait être faite de manière indiscutable, les structures et les points de référence ont été marqués sur les crânes. Les mesures linéaires et angulaires ont été faites sur des téléradiographies de profil prises dans des conditions normalisées.

D'après les résultats obtenus en se basant sur l'inspection directe des crânes, la fermeture de la synchondrose sphéno-occipitale se fait après l'éruption de la totalité des canines, des prémolaires et des secondes molaires. Les résultats obtenus par tomographies concordant très mal avec ceux de l'observation directe, la méthode tomographique doit être considérée comme peu digne de confiance.

Les mesures des changements de dimensions des structures de la région de la selle turcique ont révélé que le point sella se déplacait en moyenne de 2 mm vers le bas et vers l'arrière par rapport au tubercule pituitaire pendant la période comprise entre la fin de l'éruption des dents temporaires et celle de l'éruption des dents permanentes. Malgré ce changement de position du point sella vers le bas et vers l'arrière, la distance entre le point sella et la face distale du cartilage de la synchondrose continuait d'augmenter jusqu'à la fin de l'éruption des canines, prémolaires et secondes molaires. Cette observation est considérée comme une preuve de l'activité de la croissance du cartilage de la synchondrose jusqu'à ce stade du développement.

ZUSAMMENFASSUNG

ZEIT DES SCHLIESSENS DER SYNCHONDROSIS SPHENO-OCCIPITALIS FESTGELEGT
AN SCHÄDELN
EIN RADIOGRAPHISCHES CRANIOMETRISCHES STUDIUM

Der Zweck dieser Untersuchung war, im Verhältnis zur Entwicklung des Zahnsystems den Zeitpunkt der angehenden Schliessung der Synchondrosis

spheno-occipitalis festzulegen, sowie die Grössenentwicklung von den einzelnen Abmessungen der Basis cranii vor dem Foramen magnum zu beschrieben.

Das Material bestand aus 132 indischen Schädeln verschiedener Entwicklungsstufen, die wie von *Björk, Krebs* und *Solow* (1964) definiert der dentalen Entwicklung gemäss angeordnet wurden. Wo auf Profilröntgenaufnahmen keine genaue Lokalisation möglich war, wurden Strukturen und Referenzpunkt auf den Schädeln markiert. Auf standardisierten Profilröntgenaufnahmen wurden lineare Messungen sowie Winkelmessungen vorgenommen. Die Schliessung der Synchondrosis spheno-occipitalis muss einer direkten Besichtigung zufolgen mit einigen wenigen Ausnahmen vermutlich nach dem Erscheinen sämtlicher Eckzähne, Prämolaren und 2 Molaren erfolgen. Eine Kontrolle mittels Tomographie ergab nur geringe Übereinstimmung, weshalb die Methode als unsicher zu betrachten ist.

Eine Untersuchung der Abmessungsänderungen im Sella turcica Bereich hatte das Ergebnis, dass sich der Sellapunkt während der Periode von voll hervorgebrochenem Milchzahnsystem bis zum voll hervorgebrochenen Dauerzahnsystem im Verhältnis zum Tuberculum sella durchschnittlich um 2 mm nach unten/hinten bewegt. Der Abstand von der Sella bis zur distalen Fläche des synchondralen Knorpels nahm trotz der nach unten/hinten Bewegung des Sellapunkts ständig zu bis DS 4-M2 (canines, premolars and second molars fully erupted). Dies ist als ein Anzeichen eines aktiven Wachsens des synchondralen Knorpels bis zu dieser Entwicklungsstufe auszulegen.

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REFERENCES

Baume J. L., 1957: A biologist looks at the sella point. Europ. orthodont. Soc. Trans. *33:* 150—159.

—»— 1958: Die Wachstumsbewegungen der Sella turcica. Dtsch. Zahn-, Mund- u. Kieferheilk. *28:* 363—371.

—»— 1961: Principles of the cephalofacial development recealed by experimental biology. Amer. J. Orthodont. *47:* 881—901.

Bergland O., 1963: The bony nasopharynx. A roentgen-craniometric study. Acta odont. scand. *21*, suppl. 35.

Björk A., 1955: Cranial base development. Amer. J. Orthodont. *41:* 198—225.

Björk A. & B. Solow, 1962: Measurements on radiographs. J. dent. Res. *41:* 671—683.

Björk A., Aa. Krebs & B. Solow, 1964: A method for epidemiological registration of malocclusion. Acta odont. scand. *22:* 27—40.

Björk A., 1964 a: Sutural growth of the upper face studied by the implant method. Europ. orthodont. Soc. Trans. *40:* 49—65.

—»— 1964 b: Käkarnas tillväxt och utveckling i relation till kranier i dess helhet. p. 1—44. I: J. J. Holst (Ed.) Nordisk klinisk odontologi 1—I. A/S Forlaget for Faglitteratur, København.

Brodie A. G., 1941: On the growth pattern of the human head. Amer. J. Anat. *68:* 209—262.

—»— 1953: Late growth changes in the human face. Angle Orthodont. *23:* 146—157.

Brodie A. G. Jr., 1955: The behavior of the cranial base and its components as revealed by serial cephalometric roentgenograms. Angle Orthodont. *25:* 148—160.

Ford E. H. R., 1958: Growth of the human cranial base. Amer. J. Orthodont. *44:* 498—506.

Geary R. C., 1935: The ratio of the mean deviation to the standard deviation as a test of normality. Biometrika. *27:* 310—332.

Irwin G. L., 1960: Roentgen determination of the time of closure of the spheno-occipital synchondrosis. Radiology. *75:* 450—453.

Krogman W. M., 1930: Studies in growth changes in the skull and face of anthropoids. Amer. J. Anat. *46:* 315—353.

Lager H., 1958: A histological description of the cranial base in macaca rhesus. Europ. odont. Soc. Trans. *34:* 147—156.

Lindegård B. & B. Sonesson, 1952: A new racial character of the lower jaw. Lunds Univ. Årsskr. *48:* 1—17.

Lysell L. & R. Filipsson, 1958: A profile-roentgenologic study of a series of medival skulls from northern Sweden. Odont. T. *66:* 161—174.

Martin R., 1928: Lehrbuch der Anthropologie. 2. Aufl. Gustav Fischer, Jena.

Massey F. J., 1951: The Kolmogorov-Smirnov test for goodness of fit. J. Amer. statist. Ass. *46:* 68—78.

Melsen B., 1967: A radiographic craniometric study of dimensional changes in the nasal septum from infancy to maturity. Acta odont. scand. *25:* 541—561.

Owen D. B., 1962: Handbook of Statistical Tables. Addison-Wesley Publishing Co. Reading, Mass.

Pearson E. S., 1931: A further development of tests of normality. Biometrika. *22:* 239—249.

Pearson, K. & T. L. Woo, 1935: Further investigations of the morphometric characters of the individual bones of the human skull. Biometrika. *27:* 424—465.

Pearson E. S. & H. O. Hartley, 1954: Biometrika Tables for Statisticians. Vol. 1. Cambridge Univ. Press.

Powell T. V. & A. G. Brodie, 1963: Closure of the spheno-occipital synchondrosis. Anat. Rec. *147:* 15—23.

Sicher H., 1952: Oral Anatomy. Ed. 2. St. Louis, Mosby Co.

—»— (Ed.), 1962: Orban's Oral Histology and Embryology. Ed. 5. St. Louis, Mosby Co.

Solow B., 1966: The pattern of cranio-facial association. A morphological and methodological correlation and factor analysis study on young male adults. Acta odont. scand. *24*, suppl. 46.

Takagi Y., 1964: Human postnatal growth of vomer in relation to base of cranium. Ann. Otol. (St. Louis). *73:* 238—247.

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