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The growing skull. Part III. Dynamics of growth of the neurocranium

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The growth characteristic of the neurocranium and the dynamics of its development were studied in 1036 children, 540 boys and 496 girls, from birth to the age of 16 years. Analysis of the individual distances showed differences in the velocity, tendency and extent of growth, maturation, and sex peculiarities. An attempt was made to estimate postpubertal development. Comparison with other authors results revealed some remarkable racial features and environmental effects. By the aid of new constructed lines it was possible to interpret the peculiar growth of the occipital region and of the posterior fossa.

In an earlier paper [6] measurements of the neurocranium from birth to late puberty were estimated in 1036 children, 540 boys and 496 girls, from birth to 16 years of age. Employing these results, in the present paper the peculiarities of development were investigated, studying the differences in the increment with age in the two sexes and, where possible, the shape of the skull. To establish developmental and racial differences, comparisons were made with the results of other authors.

Materials and Method

The present study was carried out using earlier data obtained by measurements on sagittal and frontal roentgenograms of the skull. On the sagittal film, two distances were constructed, one in horizontal and one in vertical direction. On the frontal radiogram seven distances were drawn (Fig. 1). The subjects ranged in age from birth to 16 years; they were divided in 26 groups with the boys and girls separated. For the present purposes the course of development was sufficiently reflected at four points of time in the neonate and at the age of three and 16 years. For general orientation the mean of all the 9 distances is shown in Table I.

From Tables II and IV it is evident that the most rapid and comparatively greatest growth occurred in the 1st year, during which the boys gained 29.21 mm or 38.54% and the girls 26.62 mm or 35.66% over the value at birth. Development was considerable till 3 years being 14.38% in boys and 15.59% in girls during the two years since birth (Table V) achieving an actual plus of 44.31 mm in boys and 42.41 mm in girls. At 16 years the corresponding values are 53.39 mm and 48.0 mm, respectively. Although girls have always smaller values than do boys, girls attain their complete development earlier than boys, with 88.35% of total growth versus the 82.84% for the boys over the three year value (Table VI).

This paper is affectionately dedicated to the memory of Professor J. Bókay Jr., who 60 years ago, on June 27th, 1924, had examined me on paediatrics

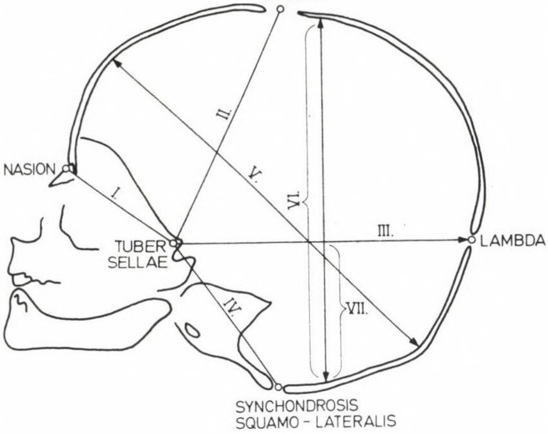

FIG. 1.

GENERAL ANALYSIS OF DISTANCES

The Tables II to V show a more intensive growth in boys than in girls. In percentual increase there are exceptions these being sometimes greater in girls than in boys and not always corresponding to actual values. For instance at 1 year of age the percentual increase in distance VII was 63.34% in girls and 60.57% in boys while the actual growth was 21.75 mm and 21.49 mm, respectively (Table IV). In distance III the growth rate at 3 years was 45.59% in boys and 47.18% in girls, while the net gain (Table II). was 38.23 mm and 38.96 mm, respectively, a negligible difference in relation to the percentual values. It is common that the velocity of growth in the first year in some distances was more pronounced than shown by the mean values, with distance VII showing the highest rate. There may be fluctuations also in percentual growth. For instance, distance II and VIII and especially distance III are some-

TABLE I

Mean length of the 9 distances, mm and σ

Age	Length			
	Boys		Girls	
	mm	σ	mm	σ
Neonate	75.79	29.29	74.65	29.37
1 year	105.0	36.7	101.27	37.39
3 years	120.10	43.49	117.06	42.65
16 years	129.28	44.31	122.65	43.14

TABLE II

Length of distances and growth of the skull, mm

No. of distance	Length at birth		Growth from birth					
			to one year		to 3 years		to 16 years	
	boys	girls	boys	girls	boys	girls	boys	girls
I	37.73	38.36	14.60	9.85	22.0	20.05	33.64	28.11
II	68.55	66.28	26.08	25.26	38.97	38.13	40.97	39.70
III	83.86	82.57	23.77	19.93	38.23	38.96	47.81	43.08
IV	49.05	47.79	22.18	21.51	33.0	30.44	43.73	37.21
V	116.95	116.86	38.71	32.85	64.78	58.36	75.90	68.64
VI	96.27	94.86	42.26	38.72	63.0	57.84	69.97	62.91
VII	35.91	33.93	21.75	21.49	32.14	30.95	38.36	35.12
VIII	96.47	94.42	37.94	37.49	53.53	54.52	65.76	61.01
IX	97.21	96.75	36.11	32.78	53.97	52.44	65.36	56.74
Mean of all 9 distances	75.79	74.65	29.21	26.62	44.31	42.41	53.49	48.0

thing forward in girls at 3 years, being surpassed by boys only by the end of the study (Table IV).

If the terminal percentual values are taken as 100% girls have at all ages some advantage except in distances I, II and V at the age of one year. It seems justified to assume that this phenomenon is a consequence of the earlier maturation of girls (Table VI).

RATE OF GROWTH OF THE DISTANCES

Distance I (Table III) connecting the sellar tuberosity and the nasion,

TABLE III

Selected values from an earlier study [6]

No. of distances	At birth		At 1 year		At 3 years		At 16 years	
	boys	girls	boys	girls	boys	girls	boys	girls
I	37.73	38.36	51.93	48.21	59.73	58.41	71.37	66.47
II	68.55	66.28	94.63	91.54	107.52	104.41	109.52	105.98
III	83.86	82.57	107.63	102.50	122.09	121.53	131.67	125.65
IV	49.05	47.69	71.23	69.0	82.05	78.23	92.78	85.0
V	116.95	116.86	155.66	149.71	181.73	175.23	192.85	185.50
VI	96.27	94.86	138.53	133.58	159.27	152.70	166.24	157.77
VII	35.91	33.93	57.66	55.42	68.05	64.88	74.27	69.05
VIII	96.47	94.42	134.41	131.91	150.00	148.94	162.23	155.43
IX	97.21	96.75	133.32	129.53	151.18	149.19	162.57	153.49

TABLE IV

Percentual growth of distances

No. of distance	From birth to one year		From birth to 3 years		From birth to 16 years	
	boys	girls	boys	girls	boys	girls
I	37.64	25.68	58.31	52.27	89.16	73.28
II	38.05	38.11	56.85	57.53	59.77	59.90
III	28.34	24.14	45.59	47.18	57.01	52.17
IV	45.22	44.38	67.28	63.70	89.15	77.86
V	33.10	28.14	55.39	49.95	64.90	58.74
VI	43.90	40.82	65.44	60.97	72.68	66.32
VII	60.57	63.34	89.50	90.10	106.82	103.51
VIII	39.33	39.71	55.49	57.74	68.17	64.62
IX	37.15	33.88	55.52	54.20	67.24	58.65
Mean of all 9 distances	38.54	35.66	58.46	56.81	70.58	64.30

TABLE V

Growth of distances in per cent

No. of distance	From birth to one year		From one to three years		From three to sixteen years	
	boys	girls	boys	girls	boys	girls
I	37.64	25.68	15.02	21.16	19.49	13.80
II	38.05	38.11	13.62	14.06	1.86	1.50
III	28.34	24.14	13.43	18.57	7.86	3.39
IV	45.22	44.38	15.19	13.38	13.08	8.65
V	33.10	28.14	16.75	17.02	6.12	5.86
VI	43.90	40.82	14.97	14.31	4.38	3.32
VII	60.57	63.34	18.02	16.38	9.14	7.05
VIII	39.33	39.71	11.60	12.91	8.15	4.36
IX	37.15	33.88	13.40	15.18	7.53	2.88
Mean of all 9 distances	38.54	35.66	14.38	15.59	7.64	4.78

TABLE VI

Per cent increase of distances between birth and 16 years taking the total value for 100%

No. of distance	Age			
	at one year		at 3 years	
	boys	girls	boys	girls
I	42.21	48.21	65.4	71.33
II	63.66	63.63	95.12	96.05
III	49.72	46.26	79.96	90.44
IV	50.72	57.00	75.46	81.81
V	51.00	47.90	85.35	85.04
VI	60.40	61.55	90.04	91.94
VII	56.70	61.19	83.79	87.04
VIII	57.69	61.45	81.40	89.36
IX	55.25	57.77	82.57	92.42
Means of all 9 distances	54.61	55.46	82.84	88.35

measures in boys 37.33 mm and in girls 38.36 mm at birth. At one year of age it is 51.93 mm in boys having grown 14.60 mm (Table II) or 37.6% (Table V) while in girls it is 48.31 mm long, 9.85 mm or 25.7% longer than at birth, the boys having reached 42.21% and the girls 48.21% of total growth (Table) VI). At 3 years the boys have reached 59.73 mm, which is 22.00 mm greater than the first value, showing a plus of 58.31%. In girls the distance is 58.41 mm, 20.05 mm or 52.27% more than at birth, 65.4% of the total growth in boys and 71.33% in girls. At 16 years distance I is 71.37 mm long in boys who show a 33.64 mm or 89.16% gain since birth. In girls the distance is 66.47 mm, corresponding to a gain of 28.11 mm or 73.28% since birth.

Distance II, running from the sellar tuberosity to the bregma measures at birth 68.55 mm in boys and 66.28 mm in girls. At one year it measures 94.63 mm, with a gain of 26.08 mm or 38.05% in boys, corresponding to 63.66% of total growth. In girls the distance is 91.54 mm, i. e. 25.26 mm or 38.1% more than at birth, having reached 63.63% of total growth. At 3 years the length is 107.52 mm in boys, 38.97 mm or 56.85% more than at birth, having achieved 95.12% of the total. In girls the length is 104.41 mm, thus 38.13 mm or 57.53% more than at birth, and 96.05% of the whole increase. At 16 years in boys it measures 109.52 mm, 40.97 mm or 59.77% more than at birth. The corresponding values in girls are 105.98 mm, 39.7 mm and 59.9%. Distance II, in boys has grown 3.54 mm more than it did in girls.

Distance III which runs from the sellar tuberosity to lambda, measures at birth 83.86 mm in boys and

82.57 mm in girls. At one year of age in boys it is 107.63 mm, i. e. 23.77 mm or 28.34 % more than at birth, having completed 49.72 % of the whole growth. In girls, the length is 102.5 mm, with 19.93 mm or 24.14 % gain, and 46.26 % of complete growth.

At 3 years distance III in boys measures 122.09 mm corresponding to a gain of 38.23 mm or 45.59 %, and 79.96 % of the total. Girls achieved 121.63 mm, which is 38.96 mm or 47.18 % more than at birth and 90.44 of the total. At 16 years in boys it is 131.67 mm, showing a gain of 47.81 mm or 57.01 %, and in girls 125.65 mm, showing a gain of 43.08 mm or 52.17 % since birth. Thus the girls have a disadvantage of 6.02 mm.

Distance IV, that between the sellar tuberosity and the squamo-lateral synchondrosis is 49.05 mm in the male and 47.79 mm in the female neonate. At one year it measures 71.23 mm in boys, being 22.18 mm or 45.22 % longer than at birth, while in girls it is 69.0 mm long, the gain being 21.51 mm or 44.38 %, making 50.72 % of the total growth in boys and 57.0 % in girls. At 3 years of age, distance IV is 82.05 mm in boys, being 33.0 mm or 67.28 % more than its one year value and 75.46 % of its whole increase. In girls it is 78.23 mm, the growth being 30.44 mm or 63.7 % more, reaching 81.81 % of the total growth. 16 years distance IV measures 92.78 mm in boys, being 43.73 mm or 89.15 % more than at birth, and 85.0 mm in girls exhibiting a gain of 37.21 mm or 77.86 %. The increase is 7.78 mm greater in boys than in girls.

Distance V means the greatest length of the skull from the frontal to the occipital region on the frontal roentgenogram. The distance in males is 116.95 mm at birth and 155.66 mm at one year, having grown 38.71 mm or 33.10 %, which is 51.0 % of the total growth. In females it is 116.86 mm at birth and 149.71 mm at one year, having grown 32.85 mm or 28.14 %, 47.9 % of the total. At 3 years it is 181.73 mm, i. e. 64.78 mm or 55.39 % more than at birth in boys, reaching 85.35 % of the total growth. In girls the distance is 175.23 mm long, 58.36 mm or 49.95 % more than in neonates, attaining 85.04 % of the total increase. At 16 years in boys it measures 192.85 mm, 75.90 mm or 64.9 % than at birth. In girls it is 185.5 mm long which means a gain of 68.64 mm or 59.7 %. Thus boys have a 7.35 mm advantage.

Distance VI is a perpendicular line constructed from the middle of distance III, and running from the inner table of the calvarium to the inner table of the occipital bone. It is 96.27 mm in the neonate boy and 138.53 mm at one year, thus 42.26 mm or 43.9 % more than at birth, reaching 60.40 of the whole growth (Table VI). In girls the distance is 94.86 mm long at birth, 133.58 mm at one year, being 38.72 mm or 40.82 % more, attaining 61.55 % of the total increase. At 3 years distance VI measures 159.27 mm in boys which is 63.0 mm or 65.4 % more than at birth, 90.04 % of the whole growth. In girls it measures

152.7 mm, 57.84 mm or 60.97% more than at birth, having reached 91.94% of the total. At 16 years distance VI is 166.24 mm in boys, i. e. 69.97 mm or 72.68% more than at birth. In girls it is 157.77 mm, the gain being 62.91 mm or 66.32%. The distance has thus grown from birth to 16 years 8.47 mm more in boys than in girls.

Distance VII is the lower half of distance VI, from the crosspoint of distance III. It measures 35.91 mm in the neonate boy and is 57.66 mm at one year, showing a gain of 21.75 mm or 60.57% and reaching 56.7% of the total growth. In girls it is 33.93 mm at birth and 55.42 mm at one year, the gain being 21.49 mm or 63.34% reaching 61.19% of the whole increase. In the three-year old boy it is 68.05 mm long, being 32.14 mm or 89.5% more than at birth, and 83.79% of the total growth. In the 3 years old girl the distance measures 64.88 mm, being 30.95 mm or 90.1% more than in the neonate, and at 87.04% of its whole growth. At 16 years it is 74.27 mm long in boys, 38.36 mm or 106.82% longer than at birth. In girls distance VII is 69.05 mm long, 35.12 mm longer and 103.51% more than at birth. Thus the boys have an advantage of 5.22 mm.

Distance VIII indicates the greatest distance between the parietal bones measured on the sagittal roentgenogram. It is 96.47 mm in boys at birth and at one year 134.41 mm, 37.94 mm or 39.33% more, having reached 57.69% of its total growth. At 3 years it is 150.0 mm, 53.53 mm or 55.49% more than at birth, having attained 81.40% of its total increase. At 16 years it is 162.23 mm, 65.76 mm or 68.17% more than at birth. In girls the values are 94.42 mm in the neonate and 131.91 mm at one year, with a gain of 37.49 mm or 39.7%, reaching 61.45% of the whole growth. At 3 years distance VIII is 148.94 mm, having grown 54.52 mm or 57.74% and achieved 89.36% of total growth. At 16 years the girls terminate with 155.43 mm which is 61.01 mm or 64.6% more than at birth. The advantage of boys is 6.80 mm.

Distance IX signifies the height of the skull on the sagittal roentgenogram, extending from the highest point to the base. In boys it is 97.21 mm at birth and at one year 133.32 mm i. e. 36.11 mm or 37.15% more, attaining 55.25% of the whole increase. At 3 years the distance is 151.18 mm long, 53.97 mm or 55.5% more than the neonatal value. At 16 years it is 162.57 mm, 65.36 mm or 67.24% longer than at birth. In girls the neonatal length is 96.75 mm, growing to 129.53 mm during the 1st year, showing a gain of 32.78 mm or 33.88%, and having reached 57.77% of the total growth. At three years distance IX is 149.19 mm, thus 52.44 mm or 54.2% more than at birth, having reached 92.42% of the whole length. At 16 years in girls it measures 153.49 mm, 56.74 mm or 58.65% more than at birth. Thus in boys distance IX is 9.08 mm longer than in girls.

Relations of distances

It is evident from the data presented above that development is not symmetrical in the different regions of the skull. There may be differences in velocity, in the extent of growth, and in maturation.

Distances I and IV are in some respects similar to each other. After considerable growth in the first year the rate is slowing down, maintaining a moderate trend till 16 years but the percentual increase is the greatest of all distances between 3 and 16 years (see Table IV). Considering the high percentual gain and the moderate percentual increase (Table VI) in the same period, being the lowest among all distances, further development may occur even after 16 years of age. Development may be expected to be more in boys considering their higher growth rate and lower maturation index. With a negligible difference in boys at 16 years the growth since birth is always more in distance IV than in distance I (Table IV), as a sign of the more active growing tendency of the occipital region as compared to distance I, i. e. the anterior fossa.

Distance II characterizes the height of the forepart of the calvarium. Its percentual growth as well as the actual increase is almost the same in boys and girls (Tables II to V). The percentual increase at 3 years is the highest among all the distances (Table VI). The second highest is distance VI. As both these distances are measuring the height of the skull, the coincidence may not be one of chance. The difference may be due to measurements of other regions and the lower part of distance VI which comprises the occipital region. Despite the differences there are considerable resemblances such as the very low percent of increase between 3 to 16 years (Table V) and the considerable percentual increase in both distances (Table VI). These indicate a more advanced maturation of these than of other distances. Considering these events the supposition seems justified that the calvarium reaches almost complete development at late puberty.

Distance III shows the most modest growth from birth to 16 years (Table IV), demonstrating the moderate removal of the lambda from the sellar tuberosity. For that reason was the end point of distance V not fixed to the lambda and the nasion which do not always reflect the maximum length of the skull.

Distance V is one of the main diameters of the skull indicating the longest one on the frontal roentgenogram. Its length at birth is almost the same in boys and girls, probably as a result of the equal compression exerted on the height and width of the skull (Table) II). It is the greatest of all distances from birth to 16 years.

While the four distances dealt with above correspond to the distances of Bergerhoff [1] and Schmid and Filthut [16] usually applied by European authors, distance V is different in some senses as mentioned in the foregoing chapter. The value obtained by the method used by us may only become greater than that of Schmid and Filthut [16] and never smaller since the distance recommended by us represents the points lying most apart. The greatest actual increase of all distances occurs in distance V, indicating the definite tendency of the skull to become long during development. This is especially expressed in boys (Table II) contrasting with the more global shape in young age and in girls. In spite of the considerable increase, the development only seems to have slowed down but not terminated. In this sense should be interpreted the mediocre values in the percentual rate of growth and the percentual increase (Tables IV and VI).

Distances VI and VII were constructed to obtain information about the growth peculiarities of the posterior fossa and the occiput. Line VI of Schmid and Filthut [16] is not suitable for the purpose and the line of Hori and Takada [10] measures only a small part of the occipital region. Still, to examine this region in detail is important; it is the seat of the cerebellum, development of which is different from that of the cerebrum. Till adolescence the cerebellum reaches the 7-fold while the cerebrum only the 4-fold of its weight at birth and a considerable part of the increase in volume extends backwards and downwards, and there must be some harmony between development of the brain and of its bony shell [13].

This part of the head has a considreable influence on balancing and holding the head. Since Homo had erected himself and started to walk on two feet the head must be balanced and held in equilibrium in the atlanto-occipital axis [11]. To understand these events, appropriate

TABLE VII

Comparison of distances (in mm) of the present study with those measured by Hori and Takada [10]

Distance	Age							
	Neonate		1 year		3 years		10 years	
	Own boys	Hori and Takada	Own boys	Hori and Takada	Own boys	Hori and Takada	Own boys	Hori and Takada
I	37.73	46.58	51.93	54.00	59.73	59.24	68.13	62.29
II	68.55	88.29	94.63	98.82	107.52	105.55	108.04	109.82
V	116.95	135.21	155.66	160.59	181.73	172.41	188.83	185.35
VIII	96.47	128.04	134.41	144.41	150.00	152.41	158.89	162.12

In column "neonate" the own boys were 0–7 day-old, while those of Hori and Takada, 0 day to 6 months of age

Designations: Present study	Hori and Takada
Distance I	anterior length
Distance II	anterior cranial height
Distance V	maximum cranial length
Distance VIII	maximum cranial breadth

weight estimations of the anterior and posterior fossa must be done along adequate lines in the occipital region. Constructing and measuring the distances VI and VII has been attempted to achieve this aim which to our best knowledge has not been studied in the literature.

Distance VI is not the longest one but showed the greatest percentual gain in both sexes. Although surpassed in actual values by distance V at 3 and 16 years, the percentual development is the second highest after distance IV (Tables IV, V). In consequence of the intense growth rate it showed a total increase of 90.04% in boys and 91.94% in girls at three years (Table VI) in spite of the diminished percentual growth after one year (Table V).

Distance VII displayed the highest growth rate, terminating at more than double of the neonatal value. The gain is more than 60% at one year in both sexes and the rate is the second highest from 3 to 16 years, with 9.14% in boys and 7.05% in girls (Table V). Owing to this rapid development of the occipital region, the equilibrium between the anterior and posterior fossae will be attained by the time when the child begins to stand up and is attempting to walk. The same tendency to achieve equilibrium and sufficient place for the rapidly developing cerebellum and cerebrum is reflected in the percentual growth rate of distance VI too, being one of the highest in the 1st year but slowing down considerably in the following years. The slowing down of the tendency of development may be explained by the inhomogeneity of the distance. The line may be regarded as containing two different parts passing through two different regions of the skull. The upper half of the line above distance III runs almost exclusively in the calvarium while the lower part determines the occipital region, measured also as distance VII.

Distance VIII is the second of the main diameters. Its length at birth is 2 mm greater in boys than in girls. Although its rate of growth is higher in girls till 3 years, the actual value becomes definitely greater in boys at 16 years (Table III, IV). The higher percentual growth of girls at three years is a result of their earlier maturation. The higher percentual increase between 3 and 16 years and the lower percent of maturation may be accepted as signs of the prolonged development of boys. Distance VIII is a component of the Retzius index (distance VIII $\times$ 100/ distance V), an important tool in establishing some characteristic features of the skull. To become a true index of the shape of the skull the value estimated in the early neonatal period is not suitable, owing to elongation the head during labour (Table VIII).

Distance IX is the third of the main diameters representing the height of main diameters representing the height of the cranium on sagittal roentgenograms. The length at birth is less than 1 mm greater in boys than in girls probably as a result of the effect of compression during labour.

The differences are more considerable in consequence of the greater percentual increment especially from birth to one year and from 3 years till 16 (Table V). The low percentual increase in girls between 3 and 16 years and the high maturation index having reached more than 9/10 of total growth at three years justifies to assume that there may only be a moderate alteration after 16 years (Tables V, VI). The situation is different in boys. The mediocre percentual growth and the low percentual total growth at three years allows to expect a further development after 16 years. Accordingly, the shape of the head of girls will be more rounded and the head of the boys more oval. This is also reflected in the width/height index being 99.29 at birth and 99.79 at 16 years in boys. The values of 97.59 at birth and 101.26 at 16 years in girls reveals clearly the tendency of the head to grow in width rather than in height.

Comparison with the results of other authors

Tscherpourkovsky [17] carried out anthropologic measurements on Russian children of pure Slavic origin from 1 to 6 months of age. He measured only three main diameters each for the two sexes. His values were smaller than those of our children and not properly comparable with our distances measured on X-ray films. Fit for comparison were his values for the width/length, the

Table VIII

Retzius index (width ×100 per length)

Age	Tscherpourkowsky		Hori and Takada	Genssler et al		Schmid and Filthut	Haas		Present study	
	boys	girls		boys	girls		boys	girls	boys	girls
0–7 days									82.49	80.79
0–14 days				80.15	80.31					
0–1 month	82.3	82.1				81.6	81.3	81.6		
0–6 months	87.4	85.2	95.87							
1 year			88.76	85.2	83.0	88.0	82.3	81.5	86.35	88.11
2 years			89.59	86.0	85.0	88.0	81.2	81.4		
3 years			88.86			88.3	81.2	81.0	82.5	85.0
10 years			87.71			86.4	81.1	80.3		
15 years						85.1	79.6	80.6		
16 years							80.6	79.6	84.12	83.8

The values of Tscherpourkowsky in the 0–6 months group should be correctly arranged as at 6 months

The indices given by Genssler et al [7] and Schmid and Filthut [16] were calculated by the present author

Retzius index (Table VIII). In the population examined by him the width seemed to grow more intensely than the length, the shape of the head becoming rather short during development.

Haas [8] measured the cephalograms of 170 boys and 150 girls. The main diameters were the same as ours but less measurements were done at longer intervals. According to Haas the greatest velocity of growth lasts till three years, being very slow after 12 years and terminating at 18 years in girls and 20 years in boys. His observation that the growth in width is greater in the first year than the growth in length is in accordance with our data and so is his statement that development is not terminated at puberty.

The lines recommended by Bergerhoff [1] were accepted by many authors. His observation that the posterior fossa grows by extension of distance IV and by a sinking of the occipital bone is supported by our findings concerning the growth of distance VII.

Hori and Takada [10] constructed own norms for measuring 382 Japanese children less than 10 years old of both sexes. They included infants from birth to six months and from seven months to 12 months in two separate groups. The rest were divided in one year and the last two in two-year groups with those of seven and eight years in one and the nine and ten years old in another group. The lines were drawn according to the recommendations of Schmid and Filthut [16]. The landmarks were fixed on the outer surface of the bone. There are interesting differences in the results. The lengths were considerably greater than in our study (Table VII) in all distances till three years, when a tendency to equalization appeared. At ten years the width of the head was more than 4 mm greater in the Japanese children while the length of the head was greater in our material.

The divergence may have many causes. Measuring length and width on the external surface of the skull will not produce differences worth mentioning. On the other hand, dividing the 0–6 years old children in one group and the 7–12 months old in another one, not respecting that the most rapid development is produced in this period, makes the values indistinguishable. This will, however, explain the differences only in the first group. For the one, 3- and 10-year groups this explanation is not sufficient but the Retzius index may offer more information. In the first age group the index shows the unusually high value of 95.87, never obtained by any European author (Table VIII). At 10 years of age the value was 87.71, having diminished slowly, indicating that Japanese children are more brachycephalic than our boys or girls, showing a racial property of the Japanese.

Schmid and Filthut [16] measured more than 15,000 children from birth to 15 years. The distances II, III, IV, and VII, the last one corresponding to our distance VIII, were drawn like in our study. Unfortunately, they did not separate boys and girls and had too long periods in the first groups. The whole first year was divided only in five groups by them and in nine groups by the present author. This might have been the reason that all their values were considerably higher than ours for the first three years when equalization begins. At 15 years the values lay halfway between our boys and girls. The equalization is a consequence of the modest growth rate, being less than in our children. However the rate of growth of distance IV is almost the same, being 76% in Schmid and Filthut's cases and 77.86% in our girls (on our boys it was higher, amounting to 89.15%). The high value given by Schmid and Filthut point to the exceptional growth tendency of the occipital region, as observed also by us. The differences in the other distances are difficult to explain. Development of the other age groups must have been retarded by the unfavourable environmental conditions and poor nourishment after World War II.

Genssler at al [7] examined children from birth to two years of age and divided them in half year groups. Most of the distances estimated by them at birth were 1–2 mm longer even in girls than those of Schmid and Filthut [16]. At 2 years the difference was 5–7 mm and in boys always even greater. The width of the head at birth was in the material of both teams the same in girls and only 1 mm more at 2 years. Our values showed greater differences.

As both teams examined children of German origin one would expect their values to be rather similar. The smaller rates of growth observed by Schmid and Filthut were probably due to environmental effects as has already been mentioned. The greater length at birth and the greater growth rates found by Genssler et al may have been the result of higher living standards and perhaps of the increasing secular acceleration since it is more than 20 years ago that Schmid and Filthut had published their results.

Brodie [3] measured the growth pattern of the head from the 3rd month of life to the 8th year. In his material the anterior and posterior parts of the head, i. e. of the cranial basis, grew at a similar rate. The lines used by this author were however, different from ours as he had chosen a central point lying outside of the sellar tuberosity. According to Brodie the configuration of the head was determined before the 3rd month of life and later growth had no influence on the shape.

Singh et al [14] reported about findings obtained by longitudinal observations of the width of the skull of 9–14-year old boys and girls. According to these authors the anterior part of the base is enlarged by development of the bone thickness and by the developing sinuses, while our measurements indicated that other factors too must have been at work. The percentual increment was equal in boys and girls while the absolute increase was smaller in girls.

Concerning the evolution of the shape of the skull, the Retzius index gives the best informations. In Table VIII our values are compared to those obtained by other authors. The first impression is the wide variety of values while there are important coincidences, too. A common feature are the low values in the first periods, probably as a result of the compressing forces during labour. Another common feature is the intensive growth in width beginning soon after neonatal age. As a consequence the skull will be rather brachycephalic. The most brachycephalic form is reached at 1 or 2 years, followed by a decrease lasting till the end of the observation, so that finally the skull becomes less brachycephalic.

In Table VIII there are some peculiarities, too. Hori and Takada [10] recorded extremely high values such as 95.87, in the first group. Thus at that period the skull would have nearly the same width and length and be over-brachycephalic. After 1 year of age the values are lower, soon becoming similar to those of Schmid and Filthut [16] but being still higher than the values of any of the other investigators. The findings of Haas [8] are also remarkable in that he observed some fluctuations but no unequivocal sign of a temporary advantage of growth in width. His values for boys and girls are nearly the same, being the least brachycephalic at the end of the observation and in certain periods they were even mesocephalic. The children of Hori and Takada seemed to have the shortest skull, with those of all other authors including our material, falling between the two.

The Retzius index is generally accepted to give reliable information concerning the shape of the skull but not about the posterior fossa although to become a general impression of the modelling of the skull as a whole that region should not be disregarded. Our distance VII seems to be appropriate to display the changes in the occipital region. According to our measurements of distance VII, this shows an extraordinary development of the posterior fossa equalizing its differences with the anterior fossa. Unfortunately, no other author has made corresponding measurements. In the paper of Bützler et al [4] there is a line corresponding to our distance VII, but their report does not contain measurements. The authors have paid little attention to the region below the line of the sellar tuberosity in spite of its task in equalizing the overweight of the anterior fossa and of its role in the development and modelling the shape of the skull.

Discussion

Our measurements are in accordance with those of earlier authors in that the head is greater in boys than in girls. All the distances are longer in the former except distance I which is 0.63 mm longer in girls at birth. It is, however, soon surpassed by boys. All authors agree in that the greater part of development is achieved in the first or in the first two years. In our material 42.21% and 63.66%, respectively, of the total increase was accomplished in the first year (Table VI). The earlier maturation of girls is reflected in having reached a higher percentage of total growth at 3 years than did the boys. The percentual increment being different in the distances may justify the supposition that the development does not terminate in all regions by 16 years. In our material the posterior fossa and the occipital region may be assumed to grow further. Persistance of the growth tendency of distance IV was demonstrated by Schmid and Filthut [16], too. In elucidating the peculiar growth of this region the newly constructed distances VI and VII proved to be of help. The observation of Martin and Saller [12] and Haas [8] that in the first year the width of the head grows more intensely than its length is in agreement with our results. The temporary change in the form of the skull is reflected by the Retzius index which is higher between 1 and 2 years of age than before or after this period. Neonates have a somewhat elongated head due probably to its compression during delivery. Compensation of the elongation is achieved only when the intensive development in width has reached a remarkable degree. It is at that time that the Retzius index shows the highest values.

The tendency to achieve equilibrium between the anterior and posterior fossae in order to keep the head balanced on the atlanto-occipital axis [11] is displayed by the rapid development of distances IV and VII. At the same time distance II has nearly completed its growth quasi as to help to create the equilibrium.

There are many data corresponding to our findings but also some divergent data. The distances recorded by German authors are in general longer than are ours. It is difficult to compare values for neonates as most of the authors observed a too long first period. The diminishing values of Schmid and Filthut [16] probably due to unfavourable environmental effects seem to be supported by the findings of Coppoletta and Wolbach [5] concerning the weight of the brain and by Holt and McIntosh [9] concerning the circumference of the skull. According to the Retzius index, Hungarian children are brachycephalic. They are halfway between the more brachycephalic type of the children of Tscherpourkowsky [17] and of those of Haas [8] who after 10 years of age are mesocephalic, Similar to ours are the children of Schmid and Filthut [16] who were somewhat more brachycephalic. The values obtained in the present study may therefore be regarded in a broader sense as racial characteristics.

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