Original Article • *Artigo Original*

Radiological determination of cranial size and index by measurement of skull diameters in a population of children in Brazil*

Determinação radiológica do índice e do tamanho craniano por mensuração dos diâmetros cranianos em uma população infantil brasileira

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Abstract
OBJECTIVE: To measure radiologically obtained skull diameters and, based on these data, calculating the cranial index and size to compare with diameter measurements and indices reported in the literature, particularly those reported by Haas. **MATERIALS AND METHODS:** The present study evaluated 732 individuals with no cranial disease, whose skull diameters were measured, Subsequently, the authors calculated the cranial index and size which demonstrate the different phases of the skull growth by inner-table to inner-table measurements. **RESULTS:** The comparative study of diameters averages by inner-table measurements has demonstrated a clearly progressive skull growth in the first year of life for both genders, and a slower growth as from the second year. Overall diameters averages did not present any significant difference between male and female individuals. **CONCLUSION:** Cranial index and size are good skull growth indicators, especially in the first four years of life, a period characterized by an accelerated growth in the first year and a moderate growth until the fourth year. After this age, a slight and stable growth occurs with a decrease in the statistical value. No statistically significant difference was found for both genders. It is recommended that mean diameters are utilized for both genders; and it is suggested that the cranial index is utilized until four years of age, and the cranial size after the age of four, as the ideal parameter for following up the skull growth.
Keywords: Cranial diameters; Cranial size; Cranial index; Childhood; Radiography.

Resumo
OBJETIVO: Realizar as medidas dos diâmetros cranianos obtidos por método radiológico e elaborar, por meio delas, o índice e o tamanho craniano, para comparar com as medidas dos diâmetros e os índices propostos por alguns trabalhos da literatura, principalmente os do estudo de Haas. **MATERIAIS E MÉTODOS:** Foram avaliados 732 pacientes sem doenças cranianas, medidos seus diâmetros cranianos e, posteriormente, formulados o índice e o tamanho craniano, que mostram as diferentes fases do crescimento do crânio, pelas medidas de tábua interna a tábua interna. **RESULTADOS:** O estudo comparativo das médias dos diâmetros, por medidas de tábuas internas, mostrou aumento do crescimento francamente progressivo no primeiro ano de vida para ambos os sexos e aumento menor a partir do segundo ano de vida. As médias globais dos diâmetros não apresentaram diferença significativa entre os sexos feminino e masculino. **CONCLUSÃO:** O índice e o tamanho craniano são bons indicadores do crescimento craniano, principalmente nos quatro primeiros anos de vida, quando o crescimento aumenta vertiginosamente no primeiro ano e, posteriormente, ocorre aumento moderado até os quatro anos de idade. Após esta idade, ocorre um leve e estável aumento e seu valor estatístico diminui. Não houve diferença estatisticamente significante, no crescimento, para ambos os sexos. Recomenda-se o uso dos valores médios dos diâmetros para ambos os sexos e sugere-se o uso do índice craniano, até os quatro anos de idade, e o tamanho craniano, após os quatro anos, sendo ideal para o acompanhamento do crescimento do crânio.
Unitermos: Diâmetros cranianos; Tamanho craniano; Índice craniano; Infância; Radiografia.

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INTRODUCTION

The radiological determination of cranial diameters in the childhood is relevant for evaluating the skull development in the pediatric and neuropediatric clinical practice. Based on these diameters, it is possible

to establish development and growth alterations, especially in the first years of life.

Studies developed by MacKinnon et al.[1], Taveras & Wood[2], Gordon[3], Cronqvist[4], Austin & Gooding[5], Gooding[6], and Haas[7] have described radiographic indices for cranial and brain sizes based on skull diameters, and correlated with age range and sex. The present study was based on the study developed by Haas, considering its highest relevance. However, it is important to note that the mentioned studies have evaluated a non-Brazilian population, in countries with low ethnic diversity, with higher socioeconomic development, and without an appropriate statistical analysis. Some of these studies lack data about the casuistic, sampling process, and evaluation of variability.

The radiological evaluation of the cranial size should be based on the skull diameter, considering that malnutrition, genetic diseases, endocrine disorders and encephalic diseases are responsible for a series of systemic changes, some of them causing retardation, and others, an abnormal skull development[2,8,9].

The cranial volume presents a four-fold increase between the birth and the adulthood, while the volume of the craniofacial region increases about 12 times[6,10]. Additionally, 80% of the postnatal skull growths occur along the first three years of life[11–14].

When the cranial index approaches the normality threshold, even in the setting of clinical neurological alterations, a plain radiological investigation may fail to detect abnormalities in the encephalic parenchyma, especially in cases where the closure of sutures and fontanelles is completed. For this reason, other diagnostic methods, such as computed tomography, should be utilized for evaluating the brain.

According to Moss & Young[15], Dorst[16] and Momose[17], the child's skull is a dynamic structure as a function of two factors affecting the skull development: the skull contents and the sutures which undergo progressive accommodation. Abnormal brain growth or early fusion of sutures results in alterations in the cranial size, affecting the encephalic parenchyma.

Radiography can be extremely useful in the assessment of the skull development, but it should be avoided for involving ionizing radiation; therefore a longitudinal radiographic study of the normal cranial growth cannot be performed.

The present study was aimed at measuring skull diameters obtained by radiological methods, and calculating the cranial index and cranial size in Brazilian children with indication for radiological investigation because of cranial trauma, with no sign of fracture.

MATERIALS AND METHODS

The present study evaluated a total of 1464 radiographs of 732 patients (428 male and 304 female) ranging in age from neonates to 18 years, with previous indication for cranial radiography for cranial traumatism. All the patients answered to an inclusion questionnaire about neuropsychomotor development and previous history of diseases, and so inclusion criteria were established. None of the patients presented any physical or cranial disease. The conventional methodology was adopted for acquisition of posteroanterior, anteroposterior and lateral views, with a 1 m source-film distance. After images acquisition, skull diameters were measured.

The fronto-occipital diameter (FO) is the measurement of the major distance between the extreme points of the frontal and occipital lobes, and skull length (L) is the major measurement perpendicular to the skull base line, i.e., the line parallel to the sphenoid sinus floor to the posterior margin of the magnum foramen, for measurements from inner table to inner table (Figure 1A). The biparietal diameter (BP) is the major measurement between parietals, from inner table to inner table (Figure 1B).

Measurements of skull diameters were evaluated by three radiologists and statistical analysis involved paired comparisons of mean diameters. No significant variation was found in relation to the method utilized ($p > 0.05$) (Table 1).

After the measurement of skull diameters of the 732 patients, Tables were prepared with mean values and standard de-
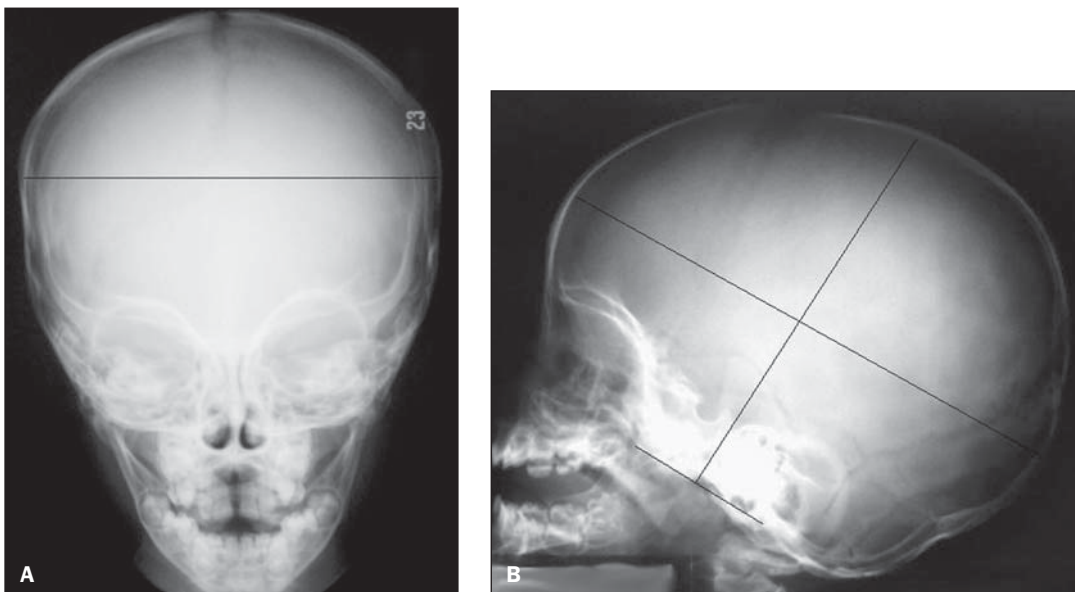

Figure 1. A: Frontal view – radiographic measurement of the biparietal diameter. **B:** Lateral view – radiographic measurements of cranial fronto-occipital diameter and cranial length.

viation for fronto-occipital and biparietal diameters, and cranial length, according to age range and sex.

A comparative analysis of the variables for each age range and according to sex was performed utilizing the Student's *t*-test for independent samples both for measurements from inner-table to inner table and from outer table to outer table.

After the data analysis, the authors opted for the measurements from inner table to inner table for demonstrating a closer proximity between the skull and brain growths.

Cranial index and size calculation was based on equations proposed by Haas, where the cranial index corresponded to the division of the width by the length transformed into percentages, and the cranial size, to the average of the three diameters, as follows:

$$\text{Cranial index} = (BP / FO) \times 100$$
$$\text{Cranial size} = (FO + BP + L) / 3$$

RESULTS

The comparative study of mean skull diameters in both sexes and according to ages, based on inner measurements is demonstrated on Tables 2, 3 and 4, where a more accelerated development in the first year, and a slower development as from the second year of life can be observed in both male and female children. It can be observed that the increase in the fronto-occipital diameter is lower in female than in male children, but mean values remain proportional for both sexes in the first year as well in the subsequent years of life, with no statistical significance.

No significant difference is found in overall mean diameters between male and female individuals in the paired mean diameters comparison by the Student's *t*-test.

After the measurement of skull diameters, cranial index and size were calculated and included respectively on Tables 5 and 6, based on the cranial module and cephalic index proposed by Haas[7], by measurements from inner-table to inner-table.

Based on the values found in the present study, the authors observed a marked decrease in the mean value for cranial index in the first year of life, and a milder decrease in the age range between four and five years,

Table 1 Comparison of paired means calculated by three observers, and respective variability (standard deviation).

Measurement	Observer 1	Observer 2	Observer 3
Fronto-occipital diameter (cm)			
Mean (standard deviation)	19.8 (0.7)	19.9 (0.7)	20.0 (0.7)
1 × 2 p = 0.159			
1 × 3 p = 0.059			
2 × 3 p = 0.285			
Biparietal diameter (cm)			
Mean (standard deviation)	16.2 (1.0)	16.3 (0.9)	16.1 (0.9)
1 × 2 p = 0.183			
1 × 3 p = 0.349			
2 × 3 p = 0.064			
Cranial length (cm)			
Mean (standard deviation)	14.4 (0.6)	14.3 (0.6)	14.7 (1.3)
1 × 2 p = 0.149			
1 × 3 p = 0.187			
2 × 3 p = 0.105			

Table 2 Cranial fronto-occipital diameter (cm), according to age and sex (inner table).

	Male			Female		
Age	Mean	Standard deviation	n	Mean	Standard deviation	n
< 3 months	13.9	1.2	12	13.2	1.1	13
3–6 months	14.9	0.6	18	14.8	0.8	16
6–9 months	16.2	0.6	14	16.0	0.7	21
9–12 months	16.6	0.5	18	16.6	1.2	13
12–18 months	17.5	0.6	13	17.3	1.2	10
18–24 months	17.4	0.6	15	17.3	0.5	8
24–30 months	18.0	1.0	19	17.7	0.9	15
30–36 months	18.4	0.7	7	18.1	0.6	9
36–42 months	18.5	0.8	19	18.2	0.7	16
42–48 months	18.7	0.8	9	18.2	0.7	12
4–5 years	18.7	0.6	37	18.5	0.8	18
5–6 years	19.5	0.8	28	18.7	0.8	21*
6–7 years	19.5	0.8	21	18.6	0.4	5[†]
7–8 years	19.3	0.8	29	19.2	0.8	19
8–9 years	19.5	0.9	22	19.3	0.7	18
9–10 years	19.5	0.8	19	19.0	1.0	18
10–11 years	19.5	0.8	24	19.3	0.7	7
11–12 years	19.0	0.7	14	19.3	0.8	11
12–13 years	19.4	0.7	14	19.5	0.7	9
13–14 years	19.4	0.9	11	18.7	0.7	11[†]
14–15 years	20.2	0.7	16	19.2	0.7	6[†]
15–16 years	20.1	0.8	14	19.4	0.9	8
16–17 years	20.0	1.0	11	19.2	0.7	7
17–18 years	19.9	0.9	14	19.6	1.4	6
18–19 years	20.1	0.9	10	19.5	1.0	7
Total			428			304

Student's *t* test for comparison of mean values.
n, No. of patients;
*p < 0.005; [†]p < 0.05.

Table 3 Cranial biparietal diameter (cm), according age and sex (inner table).

Age	Male			Female		
	Mean	Standard deviation	n	Mean	Standard deviation	n
< 3 months	11.9	1.4	12	11.4	1.4	13
3–6 months	12.8	0.8	18	12.7	0.9	16
6–9 months	13.4	0.4	14	13.4	0.7	21
9–12 months	13.3	0.7	18	13.5	0.7	13
12–18 months	14.4	0.5	13	13.6	0.7	10*
18–24 months	13.9	0.5	15	14.0	0.6	8
24–30 months	14.4	0.7	19	14.1	0.8	15
30–36 months	14.7	0.7	7	14.2	0.6	9
36–42 months	15.0	0.7	19	14.6	0.7	16
42–48 months	15.1	0.9	9	14.8	0.5	12
4–5 years	15.0	0.6	37	15.1	0.6	18
5–6 years	15.6	0.5	28	15.2	0.5	21*
6–7 years	15.8	0.7	21	15.7	0.5	5
7–8 years	15.8	0.7	29	15.5	0.8	19
8–9 years	16.1	0.5	22	15.7	0.6	18*
9–10 years	16.3	0.6	19	15.5	0.5	18†
10–11 years	16.0	0.7	24	15.5	0.6	7
11–12 years	16.0	0.9	14	15.9	0.9	11
12–13 years	15.8	0.4	14	15.9	0.6	9
13–14 years	16.1	0.6	11	15.4	0.8	11*
14–15 years	16.7	0.5	16	16.1	0.7	6*
15–16 years	16.4	0.8	14	16.1	0.7	8
16–17 years	16.5	0.9	11	16.1	0.8	7
17–18 years	16.3	0.7	14	16.0	1.2	6
18–19 years	16.4	0.5	10	16.1	0.4	7
Total			428			304

Student's t test for comparison of mean values. n, No. of patients; *p < 0.05; †p < 0.001.

Table 4 Cranial length (cm), according age and sex (inner table).

Age	Male			Female		
	Mean	Standard deviation	n	Mean	Standard deviation	n
< 3 months	12.0	1.2	12	11.3	1.5	13
3–6 months	12.6	0.5	18	12.5	0.8	16
6–9 months	13.1	0.5	14	13.1	0.6	21
9–12 months	13.3	0.6	18	13.4	1.0	13
12–18 months	13.6	0.6	13	13.3	0.5	10
18–24 months	13.7	0.6	15	13.8	0.6	8
24–30 months	14.1	0.8	19	14.1	0.8	15
30–36 months	13.9	0.4	7	13.8	0.2	9
36–42 months	14.4	0.5	19	14.4	0.6	16
42–48 months	14.6	0.6	9	14.2	0.6	12
4–5 years	14.6	0.6	37	14.5	0.9	18
5–6 years	15.2	0.5	28	14.8	0.8	21
6–7 years	15.1	0.6	21	15.4	0.4	5
7–8 years	15.4	0.6	29	14.8	1.0	19*
8–9 years	15.4	0.8	22	15.2	0.7	18
9–10 years	15.6	0.5	19	15.1	0.8	18*
10–11 years	15.3	0.7	24	15.2	0.4	7
11–12 years	15.0	0.8	14	14.9	0.8	11
12–13 years	15.3	0.5	14	15.4	0.6	9
13–14 years	14.9	0.8	11	14.7	0.8	11
14–15 years	15.5	0.6	16	15.2	0.8	6
15–16 years	15.5	0.8	14	15.7	0.5	8
16–17 years	15.7	0.7	11	16.1	1.0	7
17–18 years	15.7	0.8	14	15.7	0.9	6
18–19 years	16.2	1.0	10	16.0	0.9	7
Total			428			304

Student's t test for comparison of mean values. n, No. of patients; *p < 0.05.

and stabilizing thereafter, as shown on Table 5 as compared with Table 7 in the study developed by Haas[7]. This is explained by the fact that, after the first year of life, the cranial index is not connected with the age, partially because the fronto-occipital diameter increases more rapidly than the other diameters, as shown on Table 2.

On the other hand, the cranial size or cranial module of Haas[7] corresponds to the average of the sum of the three diameters measured from inner-table to inner-table, and increases as the diameters. In the first year of life, mean values present a higher increase, and later, a lower increase up to the age of four, stabilizing thereafter up to the age of 18, as shown on Table 6 as compared with Table 8.

DISCUSSION

Amongst the studies considered for comparison with the results of the present study, the one developed by Haas[7], evaluating the cephalic index and cranial module, has presented the most satisfactory results in the comparative data analysis.

Based on the measurements of skull diameters performed in the present study, the authors could observe that some cranial indices are good indicators of the skull growth and can be utilized in the follow-up of the cranial development.

Computed tomography is undoubtedly an excellent method for encephalic evaluation, but is ineffective in the follow-up of the skull development, considering the impossibility of determining the same positions and sizes of all structures involved for measurement of cranial diameters[9,12].

Regarding the history of the skull growth, Haas[7] has studied 1427 European patients ranging in age from neonates to 21 years, included in a sample slightly larger than the samples of the other mentioned studies, but with no miscegenation. The author has utilized a 97.0 cm source-film distance, while the recommended distance is 100 cm. Haas does not report the positioning of the skull for images acquisition, and mentions the central ray angulation in relation to the imaged skull. Additionally, his sample for the first year of life (when the skull growth is more accelerated) includes 23 patients, while the skull diameters de-

Table 5 Cranial index (%) in the present study, according to age and sex (inner table).

Age	Male			Female		
	Mean	Standard deviation	n	Mean	Standard deviation	n
< 3 months	85.3	5.2	12	86.1	7.1	13
3–6 months	85.7	4.9	18	85.5	6.7	16
6–9 months	82.8	4.2	14	84.1	3.5	21
9–12 months	80.0	3.3	18	81.7	4.8	13
12–18 months	82.0	3.2	13	78.6	3.5	10*
18–24 months	79.6	3.8	15	81.1	4.5	8
24–30 months	80.2	4.3	19	79.6	5.0	15
30–36 months	79.9	3.5	7	78.7	3.1	9
36–42 months	81.1	5.1	19	80.3	3.7	16
42–48 months	80.9	2.5	9	81.7	4.0	12
4–5 years	80.7	2.9	37	81.8	4.3	18
5–6 years	80.1	3.8	28	81.5	4.6	21
6–7 years	81.1	3.2	21	84.6	4.2	5
7–8 years	82.2	3.4	29	81.1	5.0	19
8–9 years	82.9	3.8	22	81.4	3.2	18
9–10 years	83.5	4.6	19	81.7	3.7	18
10–11 years	82.5	3.9	24	80.1	3.8	7
11–12 years	84.7	4.1	14	82.5	5.4	11
12–13 years	81.2	2.5	14	81.4	4.3	9
13–14 years	83.1	3.2	11	82.4	4.4	11
14–15 years	82.5	4.1	16	83.9	5.1	6
15–16 years	81.7	4.2	14	83.3	2.4	8
16–17 years	82.9	5.2	11	83.5	3.9	7
17–18 years	82.3	4.5	14	82.0	4.5	6
18–19 years	81.9	4.6	10	82.4	4.8	7
Total			428			304

Student's *t* test for comparison of mean values. *n*, No. of patients; *p < 0.05.

Table 6 Cranial size (cm) in the present study, according to age and sex (inner table).

Age	Male			Female		
	Mean	Standard deviation	n	Mean	Standard deviation	n
< 3 months	12.6	1.2	12	12.0	1.3	13
3–6 months	13.4	0.5	18	13.3	0.6	16
6–9 months	14.3	0.4	14	14.1	0.6	21
9–12 months	14.4	0.5	18	14.5	0.9	13
12–18 months	15.1	0.4	13	14.7	0.7	10
18–24 months	15.0	0.4	15	15.0	0.4	8
24–30 months	15.5	0.7	19	15.3	0.7	15
30–36 months	15.7	0.5	7	15.4	0.4	9
36–42 months	16.0	0.4	19	15.8	0.5	16
42–48 months	16.1	0.7	9	15.7	0.5	12
4–5 years	16.1	0.5	37	16.0	0.5	18
5–6 years	16.7	0.4	28	16.2	0.5	21*
6–7 years	16.8	0.6	21	16.6	0.1	5
7–8 years	16.8	0.5	29	16.5	0.7	19
8–9 years	17.0	0.6	22	16.7	0.5	18
9–10 years	17.1	0.4	19	16.5	0.6	18*
10–11 years	16.9	0.6	24	16.7	0.3	7
11–12 years	16.7	0.5	14	16.7	0.6	11
12–13 years	16.8	0.4	14	16.9	0.4	9
13–14 years	16.8	0.6	11	16.2	0.5	11†
14–15 years	17.5	0.3	16	16.8	0.5	6*
15–16 years	17.3	0.6	14	17.1	0.6	8
16–17 years	17.4	0.6	11	17.1	0.7	7
17–18 years	17.3	0.6	14	17.1	1.0	6
18–19 years	17.6	0.6	10	17.2	0.5	7
Total			428			304

Student's *t* test for comparison of mean values. *n*, No. of patients; *p < 0.005; †p < 0.05.

termined in the present study refer to a sample including 62 patients in their first year of life, justifying a larger sample size, indicating more reliable measurements and statistical evaluations.

The skull growth is quite accelerated in the first year of life, as demonstrated by the increase in cranial diameters on the tables included in the present study. Changes in the cranial diameters slow down after the first three years of life, and are associated with a 25% increase in the encephalic weight, according to MacKinnon et al.[1].

The comparison between cranial indices calculated in the present study and the one developed by Hass[7] demonstrated practically the same result, with no statistical significant difference. However, our study presented a larger casuistic, a better ethnic diversity, and better statistical analysis.

These indices are not useful in the evaluation of a possible encephalic involvement, but rather to follow-up the cranial development.

CONCLUSION

The cranial index evaluated in the present study is a good indicator of the skull growth, especially in the first four years of life, when the skull grows more rapidly. After this age, considering the decrease and stabilization in the growth velocity and the decreased statistical value, the cranial size or tables with skull diameters become better indicators for following-up the skull development both in female and male individuals.

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Table 7 Cephalic module developed by Haas (inner table to inner table).

Age	Male				Female				Total			
	n	V_{min}	V_{max}	M	n	V_{min}	V_{max}	M	n	V_{min}	V_{max}	M
–4 weeks	4	11.6	12.3	12.0	3	10.8	12.8	11.6	5	10.8	12.3	11.8
2–6 months	8	11.9	14.6	12.9	7	12.1	14.1	12.7	15	11.9	14.6	12.8
7–12 months	11	13.0	15.3	14.9	12	12.9	15.0	13.8	23	12.9	15.3	14.2
13–18 months	9	14.3	16.1	15.3	17	13.5	16.0	14.8	26	13.5	16.1	15.0
19–30 months	23	14.5	16.8	15.9	12	13.6	16.6	15.1	35	13.6	16.8	15.7
3–5 years	33	14.8	17.4	16.3	26	14.2	17.4	16.0	59	14.2	17.4	16.2
6–8 years	29	15.5	17.7	16.8	27	14.3	17.5	16.3	56	14.3	17.7	16.6
9–11 years	30	15.7	18.1	16.9	23	15.2	17.6	16.5	53	15.2	18.1	16.7
12–14 years	30	16.4	18.5	17.4	23	16.0	17.6	16.7	53	16.0	18.5	17.1
15–17 years	32	16.6	18.8	17.6	18	15.9	17.7	16.9	50	15.9	18.8	17.3
18–20 years	30	16.3	19.2	17.7	22	16.3	17.8	17.1	52	16.3	19.2	17.5
	360	16.3	19.5	17.8	355	15.7	18.5	17.1	715	15.7	19.5	17.5
	s = –0.52+0.51 M ± s = 17.3–18.4 = 72.1% M ± 2s = 16.8–18.9 = 94.2%				s = –0.54 + 0.39 M ± s = 16.4–17.6 = 70.2% M ± 2s = 16.0–18.1 = 95.7%							
Total	597				545				1.142			

V_{min}, minimum value; V_{max}, maximum value; M, mean; s, standard deviation.

Table 8 Cephalic index according to Haas (inner table to inner table).

Age	Mean	Standard deviation	Minimum / maximum	n
< 3 months	85.7	6.1	74.2 / 97.5	25
3–6 months	85.6	5.7	74.7 / 99.3	34
6–9 months	83.6	3.8	77.1 / 91.4	35
9–12 months	80.7	4.0	71.9 / 86.7	31
12–18 months	80.5	3.7	75.3 / 88.9	23
18–24 months	80.1	4.0	74.4 / 88.2	23
24–30 months	79.9	4.6	72.9 / 92.4	34
30–36 months	79.2	3.2	74.3 / 84.7	16
36–42 months	80.7	4.4	72.6 / 92.4	35
42–48 months	81.3	3.4	76.4 / 90.6	21
4–5 years	81.0	3.5	73.4 / 88.2	55
5–6 years	80.7	4.2	73.7 / 89.3	49
6–7 years	81.8	3.6	74.0 / 88.9	26
7–8 years	81.7	4.1	73.2 / 94.5	48
8–9 years	82.2	3.6	73.9 / 90.4	40
9–10 years	82.6	4.3	76.5 / 93.4	37
10–11 years	82.0	4.0	71.9 / 90.0	31
11–12 years	83.7	4.8	70.8 / 92.7	25
12–13 years	81.3	3.3	74.4 / 86.8	23
13–14 years	82.7	3.8	77.7 / 90.2	22
14–15 years	82.9	4.3	76.4 / 90.6	22
15–16 years	82.3	3.6	77.5 / 90.3	22
16–17 years	83.2	4.6	75.5 / 90.4	18
17–18 years	82.2	4.4	73.4 / 90.7	20
18–19 years	82.1	4.5	73.9 / 91.0	17
Total				732

n, No. of patients.

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