Original article

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Argentine reference charts for head circumference from birth to 19 years of age

Mariana del Pino[a], *Sofía Chiaramonte*[a], *Alicia B. Orden*[b]

ABSTRACT

Introduction. Head circumference (HC) is an indicator of brain growth; growth charts are necessary to determine normal or pathological variations.

Objectives. To present the first Argentine HC reference charts between birth and 19 years of age and to compare them with the Nellhaus charts, which have been used in our country to date.

Population and methods. These references were developed based on combined data from the National Survey on Nutrition and Health of 2018 and cross-sectional studies conducted between 2004 and 2007 in the provinces of Buenos Aires and La Pampa, which included 8326 healthy children and adolescents. Growth curves were adjusted using the LMS method. To assess the differences between these reference charts and the Nellhaus charts, at different ages, the 2nd, 50th, and 98th percentiles were plotted.

Results. HC showed a variable increase in size with age, which was greater in the first years of life, and a slight increase at puberty. The values for the 98th percentile of the Argentine reference charts were higher than those of the Nellhaus charts at all ages. The values for the 2nd percentile of the national reference were lower than those of the Nellhaus charts during the first 2 years of life, similar between 3 and 7 years of age, and higher after this age.

Conclusions. The Argentine curves adequately describe the growth pattern of HC. The differences found with the Nellhaus charts may be attributed to secular changes.

Keywords: *head; cephalometry; growth charts; reference standards.*

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[a] *Department of Growth and Development, Hospital de Pediatría S.A.M.I.C. Prof. Dr. Juan P. Garrahan, City of Buenos Aires, Argentina;* [b] *Fundación Centro de Salud e Investigaciones Médicas (CESIM), Santa Rosa, Argentina. National Scientific and Technical Research Council (Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET), City of Buenos Aires, Argentina.*

Correspondence to *Mariana del Pino: mdelpino@garrahan.gov.ar*

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INTRODUCTION

Growth charts are widely used in pediatric clinical practice to assess anthropometric measurements that vary with age; they are usually developed to represent the growth of a population.[1] The use of a universal reference to assess child growth is based on the idea that the greatest inter-population variations in growth occur due to environmental effects.[2] This idea supported the creation of the growth standards published by the World Health Organization (WHO) in 2006.[3] The WHO growth standards for children aged 0-59 months are the result of an international multicenter study (Multicentre Growth Reference Study, MGRS) conducted between 1997 and 2003 in 6 countries (Brazil, Ghana, India, Norway, Oman, and USA). That study included healthy children who were exclusively or predominantly breastfed and grew up in optimal socioeconomic conditions.[3,4] Since their publication, the WHO child growth standards for children aged 0 to 5 years have been adapted and used in more than 100 countries.[5] In Argentina, in 2007, the National Ministry of Health and the Sociedad Argentina de Pediatría adopted, by Resolution 1376, the new WHO growth curves for the follow-up and care of children in the first 5 years of life[3] and their subsequent introduction in the Guideline for the Assessment of Growth.[6]

Argentina has national reference charts for weight and height for age,[7] which have been validated in children and adolescents.[8,9] In 2009, these reference charts were adjusted by the LMS method, incorporating the WHO standard databases for body weight and length for infants and toddlers aged 0 to 2 years,[10] which are used for the auxological assessment of children and adolescents up to 18 years of age. However, our country does not have its own reference charts for the assessment of head circumference (HC) for age, so the Sociedad Argentina de Pediatría recommended the use of the Nellhaus charts,[11] which have been applied to date for the assessment of head growth in children born at term, during childhood and adolescence. The Nellhaus charts contain HC percentiles from birth to 18 years estimated from data published in the literature since 1948.

Some studies have shown secular changes in HC,[12,13] so the use of reference charts developed from data collected more than 50 years ago may lead to misdiagnosis, unnecessary referrals, and invasive tests due to overdiagnosis of macrocephaly, while some children with true microcephaly may go undetected.[14–16]

This study estimated the HC percentiles of Argentine children and adolescents aged 0 to 19 years and compared them with the Nellhaus charts.[11]

POPULATION AND METHODS

HC percentiles for age were estimated using a retrospective, descriptive, and observational design based on data from (a) a cross-sectional sample of 4022 healthy children aged 0.01 to 2.00 years of decimal age assessed in the Second National Survey on Nutrition and Health;[17] (b) a cross-sectional sample of 624 healthy boys and girls aged 2 to 14 years assessed in private and public schools in the city of La Plata and Greater La Plata (Buenos Aires) during 2005; and (c) a cross-sectional sample of 3680 boys and girls aged 3 to 19 years who were attending private and public schools in the city of Santa Rosa (La Pampa) in the 2004–2007 period. HC data from samples b and c were previously used for the development of the Argentine reference charts for the HC/height index.[18] Children with a history of prematurity (gestational age < 37 weeks), low birth weight for gestational age according to the Intergrowth standards,[19] children with a current or previous diagnosis of malnutrition/underweight according to anthropometric indicators or who had a history of previous diagnosis of malnutrition, a history of multiple pregnancy, unknown gestational age or birth weight, and a history of maternal smoking during pregnancy were excluded.

HC was measured in each sample according to the standardized procedures reccomended by Sociedad Argentina de Pediatria.[6]

Data analysis and processing

Scatter and box plots were constructed to eliminate outliers. HC data comprised between the mean ± 4 standard deviations (SDs) were included to estimate percentiles.

HC percentiles for age were estimated using the LMS method. This method allowed to adjust the asymmetry using a Box-Cox transformation (L), that normalizes data distribution at each age,[20,21] considering the median (M) and the coefficient of variation of distribution (S). A property of the proposed LMS model is that, when fitted with data, the estimated L, M, and S values will change smoothly at the t-axis (age), so that they are be representative of the population with smoothed curves plotted as a function of the y-axis (HC). At each age, HC distribution is

summarized into 3 coefficients: L, M, and S, where L accounts for the asymmetry; M, for the median; and S, for the coefficient of variation for each age and sex. These parameters were estimated according to the maximum penalized likelihood procedure.[21,22] Percentiles were estimated based on the following formula:[20,22]

$C_{100\alpha(t)} = M(t)\ (1 + L(t)\ S(t)\ Z\alpha)1/L(t)$, where:
$C_{100\alpha(t)}$ is the HC percentile corresponding to Zα.

Zα is the quantile (percentile) 100α of the standard normal distribution.

t is age in years.

L(t): asymmetry, M(t): median, S(t): coefficient of variation, and $C_{100\alpha(t)}$ indicate the values corresponding to each t age curve. The estimated L(t) value was 1 in all cases.

The normality of the residuals was assessed using the Q-Q plot, and the Q-test was applied to assess the goodness-of-fit.[22,23] The LMSChartMakerPro software was used for statistical processing.[24]

To assess the magnitude of the differences between the Argentine reference charts and the Nellhaus charts[11] at different ages, the 2nd, 50th, and 98th percentiles of both references were plotted.

This research study (no. 1568) was approved by the Research and Ethics Committee of Hospital Garrahan (11/21/2023).

RESULTS

The final sample included 4269 boys and 4057 girls. *Table 1* shows the sample composition by sex and age group. *Tables 2* and *3* show the L, M, and S values together with the 3rd and 97th percentiles for both sexes. *Supplementary tables 1* and *2* show the values for the 2nd, 3rd, 10th, 25th, 50th, 75th, 90th, 97th, and 98th percentiles for both male and female.

The degree of adjustment of the reference curve is expressed as equivalent number of degrees of freedom (edf). For boys, the parameters of the adjusted curve were L0 (1), M 8.3, S 3.1 R edf. For girls, the parameters of the adjusted curve were L0 (1), M 8.3, S 3.1 R edf. The distribution was normal for each age. *Supplementary figure 1* shows the Q-test plots for male and female subjects, where L, M, and S values are within the +/- 2 range, indicating an adequate adjustment for the selected model.

Figures 1 and *2* show the HC reference curves for male and female children and adolescents aged 0 to 19 years, respectively, in the 7 percentile format (3rd, 10th, 25th, 50th, 75th, 90th, and 97th). For males, at 4 days of life, HC reaches 64% of their adult size. In the first year of life, HC reaches 81% of their adult size and, at 5 years, 90%. From 5 years until puberty, HC growth an additional 5% and it reaches its final size around 18 years of age. For females, these values correspond to 65% of their adult size at 4 days of life; 82% at 1 year, and 91% at 5 years of age. As in boys, HC increases an additional 5% between 5 years old and puberty and reaches 100% at 17 years.

Supplementary figures 2 a and *b* show raw data for percentiles adjusted by the LMS method for boys and girls.

Supplementary figures 3 a and *b* show the 2nd, 50th, and 98th percentiles of the Argentine reference charts and those corresponding to the Nellhaus charts.

In both males and females, the 98th percentiles corresponding to the Argentine reference charts were higher than those of the Nellhaus charts[11] in all age groups. Also compared to the Nellhaus charts,[11] the 2nd percentiles corresponding to the Argentine reference charts were lower until 2 years of age, similar between 3 and 7 years of age, and higher as of that age.

DISCUSSION

This study describes the first Argentine HC reference charts developed with updated data, especially during the first 2 years of life. This

Table 1. Sample composition by sex and age group

Age, years old	Males	Females	Total
0.01 to 1.99	2085	1937	4022
2.00 to 5.99	266	228	494
6.00 to 9.99	783	700	1483
10.00 to 14.99	1028	1080	2108
15.00 to 19.00	107	112	219
Total	4269	4057	8326

Table 2. 3rd and 97th percentiles and L, M (50th percentile), and S values for head circumference in males 0 to 19 years of age

Age	L	M (50th percentile)	S	3rd	97th
0.01	1	36.73	0.047	33.49	39.97
0.5	1	43.82	0.042	40.39	47.24
1	1	46.82	0.037	43.60	50.05
2	1	48.95	0.031	46.13	51.77
3	1	50.59	0.028	47.88	53.29
4	1	51.43	0.028	48.75	54.11
5	1	51.84	0.027	49.17	54.51
6	1	52.19	0.027	49.52	54.85
7	1	52.62	0.027	49.95	55.28
8	1	53.05	0.027	50.39	55.72
9	1	53.46	0.026	50.80	56.12
10	1	53.88	0.026	51.22	56.54
11	1	54.27	0.026	51.61	56.94
12	1	54.68	0.026	52.01	57.35
13	1	55.18	0.026	52.51	57.86
14	1	55.76	0.026	53.07	58.44
15	1	56.29	0.025	53.60	58.98
16	1	56.72	0.025	54.02	59.41
17	1	57.09	0.025	54.39	59.78
18	1	57.44	0.025	54.74	60.14
19	1	57.79	0.025	55.08	60.49

L: asymmetry; M: median; S: coefficient of variation.

Table 3. 3rd and 97th percentiles and L, M (50th percentile), and S values for head circumference in females 0 to 19 years of age

Age	L	M (50th percentile)	S	3rd	97th
0.01	1	35.97	0.049	32.63	39.31
0.5	1	42.54	0.044	39.00	46.09
1	1	45.87	0.040	42.45	49.29
2	1	47.93	0.034	44.91	50.96
3	1	49.40	0.031	46.54	52.26
4	1	50.36	0.030	47.55	53.17
5	1	50.83	0.029	48.03	53.62
6	1	51.19	0.029	48.41	53.97
7	1	51.63	0.028	48.86	54.39
8	1	52.11	0.028	49.36	54.86
9	1	52.61	0.028	49.88	55.34
10	1	53.11	0.027	50.40	55.82
11	1	53.63	0.027	50.94	56.32
12	1	54.21	0.026	51.54	56.88
13	1	54.70	0.026	52.05	57.35
14	1	54.98	0.026	52.34	57.62
15	1	55.16	0.025	52.53	57.80
16	1	55.28	0.025	52.65	57.91
17	1	55.37	0.025	52.75	58.00
18	1	55.49	0.025	52.87	58.11
19	1	55.61	0.025	53.00	58.22

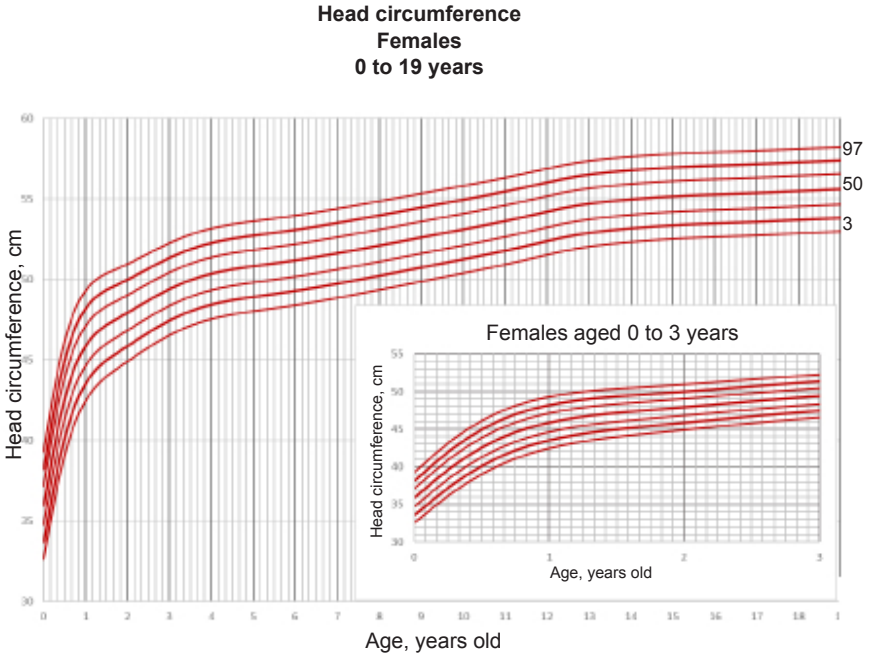
L: asymmetry; M: median; S: coefficient of variation.

is the period with the highest rate of postnatal head growth; therefore, the timely detection of any alteration in size or growth in this period is of great importance due to the implications that this entails.

HC growth peaks between 15 and 17 weeks

Figure 1. Reference curves for head circumference from 0 to 19 years of age, males

Figure 2. Reference curves for head circumference from 0 to 19 years of age, females



of gestation. Such high rate is maintained until approximately 32–34 weeks of gestation, after which it begins to slow rapidly.[25] Our data are compatible with the postnatal growth pattern described in the literature. In the first week of life, HC is, on average, 36.7 cm in males and 35.9 cm in females. During the first year of life, it increases rapidly (10 cm on average) and reaches 81–82% of its adult size. This is the period of greatest growth rate, and of greatest deceleration. Between 12 and 24 months of age, the average HC increase reduces to 2 cm and, between 24 and 36 months of age, to 1.5 cm in both sexes. Thus, at 3 years of age, HC reaches 88–89% of

its adult size in males and females, respectively. Thereafter, the changes in HC occur at a lesser but constant rate until puberty, when there is a slight increase, earlier in females (10 to 11 years of age) than in males (12 to 13 years of age). In contrast to childhood, when HC reflects brain growth, during adolescence, changes in HC are less than 2% and do not reflect variations in brain size,[26] but rather changes in the thickness of the skull and scalp.[27] There were sex differences in *tempo* of growth, being girls more advanced than boys.

Monitoring head growth involves the use of standardized tools to determine whether growth is adequate, abnormally large or small for age.[28,29] This study provides the first HC reference chart for the Argentine population, providing the current percentiles in our population of children and adolescents aged 0 to 19 years. These cross-sectional reference charts may also be used for national and international comparisons, or to assess secular changes. The comparison with the Nellhaus charts[11] showed that the national curves were higher than these curves, except for the 2nd percentile in the first 2 years, where they were similar or slightly lower. The comparison of the 98th percentile showed higher values in the Argentine reference charts, except at 24 months old in males (-0.3 cm). Such differences from the Nellhaus charts[11] may be interpreted as a secular trend, taking into account that the latter were developed with data collected more than 50 years ago.

It is worth noting some of the limitations of this study. One is the smaller number of data between 2 and 5 years of age and in adolescents older than 15 years, which did not prevent a good adjustment of the percentiles. Another limitation is that, for children older than 2 years, not all the country regions were represented, where variations in the genetic composition of the population or other environmental conditions may influence head size. However, the anthropometric data used to develop the reference charts were collected from a healthy population, by trained personnel and in accordance with the standards proposed by the Sociedad Argentina de Pediatría.[30] In addition, having a population of more than 1000 data per age group and sex in the first 2 years of age allowed us to perform an adequate curve adjustment at this end of the data range, where the growth rate is accelerated, thus determining that the sample is adequate for the development of HC reference charts. Finally, an additional advantage over the Nellhaus charts[11] is that, in the Argentine reference charts, the LMS method was used to estimate and summarize the HC curves so that measurements can be transformed into Z-scores, which will allow comparisons with other populations.

CONCLUSIONS

This study provides the first Argentine HC reference charts, which were constructed with a population of children and adolescents without known disorders affecting growth, with an updated data sample, especially in the first 2 years of age. These reference charts will be a very useful tool to assess head circumference growth in our population. ■

Supplementary material available at: https://www.sap.org.ar/docs/publicaciones/archivosarg/2024/10296_AO_delPino_Anexo.pdf

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