A Study of Family Head Shape: Environment Alters Cranial Shape

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Summary: A change in the type of cranial deformities (plagiocephaly) presenting to certain clinics has occurred. The purpose of this study was to compare infant head shapes against head shapes of their biologic parents to explore the roles of heredity and environment on cranial shape. Standardized family photographs and anthropometric measurements demonstrated that 30% of the infants had cranial widths 2 standard deviations above norm, while 4.6% had widths exceeding 3 standard deviations. Despite a mean age of only 8 months, 11.6% had widths that were already greater than that of 1 parent. These results demonstrate that plagiocephaly has taken on a new configuration, presenting not only with asymmetry, but also with excessive cranial width.
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Introduction

In 1994, Huang and associates published a landmark study that demonstrated that a differential diagnosis between deformational plagiocephaly and lambdoid synostosis could be achieved without the use of computed tomography (CT) scans or radiography.[1] Huang and colleagues argued that a thorough clinical evaluation of the head shape would reveal the origin of the deformity because these 2 conditions produce remarkably different head shapes that are clearly distinguishable from the vertex position. This study is credited with classifying deformational plagiocephaly as a parallelogram deformity, because when viewed from the vertex position, this is the shape that is observed. In contrast, lambdoid synostosis takes on the shape of a trapezoid that has been tipped on one side (i.e., the longer axis runs along one side of the head). Because the head shapes produced by these conditions are so well-defined, CT scans and radiographs are typically only required if patency of a suture remains in question.

In recent years, however, the head shape associated with deformational plagiocephaly has taken on a new configuration that may not be so easily differentiated. Today, infants present not only with significant asymmetry (i.e., a parallelogram deformity), but also with excessive cranial width, a shortened skull base, and increased posterior head height (brachycephaly) (Figures 1, 2).

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The purpose of this study was to document this change in cranial morphology, and compare infant head shapes against head shapes of their biologic parents to explore the roles of heredity and environment on cranial shape.

Methods

Between January and April 2003, a prospective, multicenter study was performed in 5 locations across the United States (Arizona, Florida, New Jersey, North Carolina, and Texas). The methods of data collection and maintenance for this study were approved by an external institutional review board (Argus Institutional Review Board, Tucson, Arizona), and informed consent was obtained from all participants.

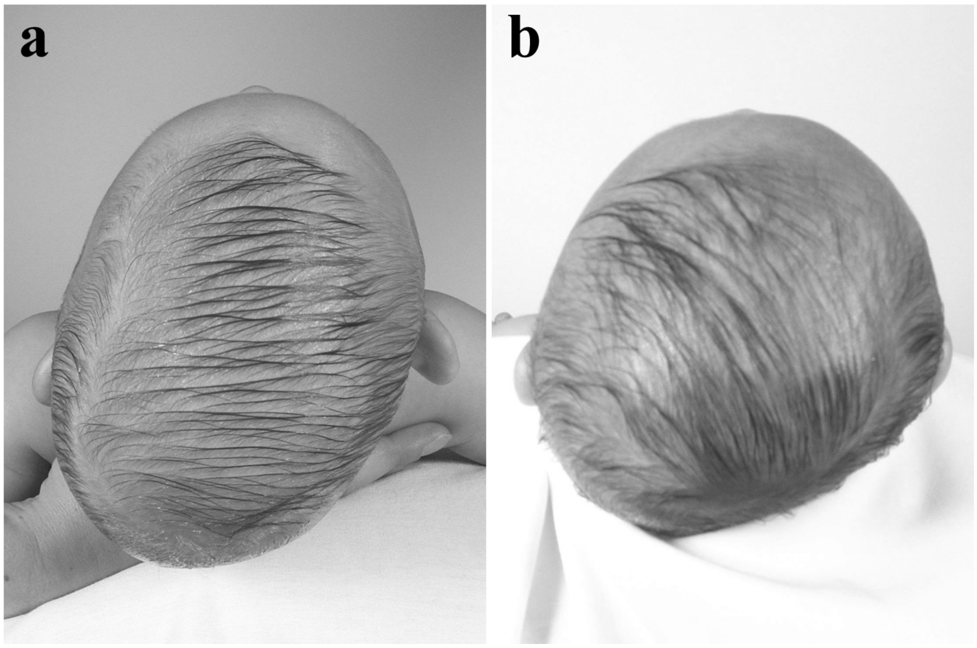

Figure 1. A. Vertex view of the classic parallelogram deformity. **B.** Vertex view of today's new wider configuration.

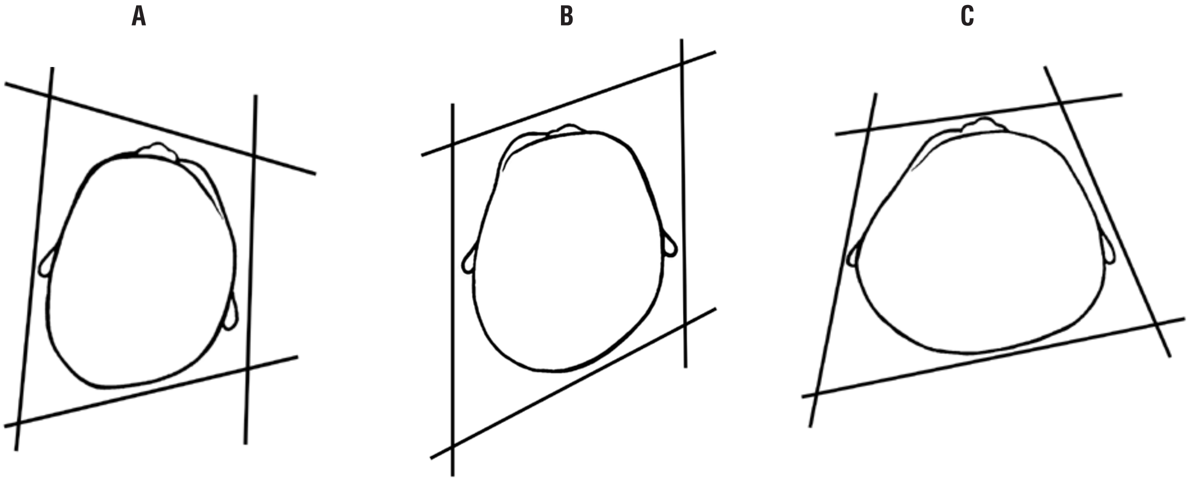

Figure 2. A. Trapezoidal shape representing lambdoid synostosis. **B.** Classic parallelogram deformity representing plagiocephaly, circa 1990s. **C.** New trapezoidal shape representing plagiocephaly today.

All families entering 1 of 5 clinics were invited to participate, with the only constraint being that the adult caregivers had to be the biologic parents of the infant. Comprehensive medical histories were obtained on all family members including information regarding age, gender, race/ethnicity, and sleeping position as infants. Family photographs were obtained and standardized to ensure objective analysis, with parents located on the outside of the image and infants in the middle. The faces of all family members were positioned at the same focal plane to minimize disparities associated with magnification and parallax. Anthropometric measurements (cranial length [g-op], cranial width [eu-eu], circumference) were collected on each family member by individuals formally trained in anthropometrics, and cephalic indices were calculated ([eu-eu/g-op] × 100) from these measurements.

The initial analyses were conducted using analysis of variance and Duncan's multiple ranges tests to evaluate among and between group differences. In addition, *t* tests were performed to determine whether participant groups varied significantly from published age and gender specific norms. Although it would have been preferable to use norms from a single source, the sample sizes for infant norms published by Farkas (1994) are approximately half those of Hajnis (1970) and do not include cephalic index. On the other hand, Hajnis (1970) did not publish adult data, while the adult samples of Farkas (1994) are robust and well known. Consequently, normative data for infants was taken from Hajnis (1970), while normative data published by Farkas (1994) was used for comparisons to their parents. Differences were considered significant if p values were less than 0.05.[2-4]

Results

Over a 4-month period, 39 families were enrolled in this study. The sample infant population (n = 43) consisted of 38 males (88.4%) and 5 females (11.6%) with a mean age of 7.8 months (SD ±2.1; range, 5 to 13 months). As anticipated, there were an equal number of adult males (n = 39) and females (n = 39) with mean ages of 33.9 and 30.5 years, respectively.

The majority of the infants were back sleepers, as compared to adults who primarily slept prone. Thirty-seven (86.0%) of the 43 infants were placed to sleep on their backs, while the remaining 6 were split evenly between sleeping on their side or in multiple positions. In contrast, only 3.9% of parents reported being slept on their backs as infants, while 61.8% were stomach slept, 5.4% were side slept, 2.6% slept in multiple positions, and the re-

Table 1

COMPARISON BETWEEN THE MEAN CRANIAL WIDTHS COLLECTED IN THIS STUDY AND THE APPROPRIATE AGE- AND GENDER-SPECIFIC NORMS (STUDENT *T* TEST)

Age Range (mo)	Gender	No. of Patients	Mean Cranial Width (mm) (SD)	Cranial Width Norm (SD)*	t Value	p Value
0–6	F	2	116.0 (1.4)	97.9 (7.0)	3.600	0.0011
	M	5	132.0 (5.7)	100.6 (10.1)	3.768	0.0001
6–12	F	3	126.0 (5.6)	118.1 (6.7)	1.964	0.0589
	M	33	127.9 (8.0)	120.3 (7.4)	3.326	0.0017
Adult	F	39	137.8 (6.9)	144.1 (5.1)	6.629	0.0001
	M	39	147.1 (7.2)	151.1 (5.7)	3.500	0.0006

*Infant norms obtained from Hajnis, 1970 and adult norms obtained from Farkas, 1994.

maining 26.3% were unsure of how they were slept as infants.

Despite collecting data on 43 sequential families, the infant sample included only 5 females. When divided into groups based on age and gender, there were only 2 female participants in the 0- to 6-month age range and 3 in the 6- to 12-month age range. Because of these small sample sizes, statistically significant conclusions cannot be drawn from the female data, but their raw data and general observations are provided for completeness.

Cranial Width

Infants had an average cranial width of 127.7 mm (SD ±7.9; range, 110 to 141 mm), while fathers and mothers had mean widths of 147.1 mm (SD ±7.2; range, 131 to 160 mm) and 137.8 mm (SD ±6.9; range, 126 to 160 mm), respectively. Analysis of variance revealed significant differences in cranial width ($p < 0.0001$), with Duncan's multiple range testing demonstrating that fathers, mothers, and infants were significantly different from each other ($p < 0.05$).

Student *t* test results revealed statistically significant differences between the mean cranial widths of specific gender and age groups when compared to their normative data (Table 1). Although both fathers' and mothers' cranial widths were significantly lower than their age- and gender-specific norms ($p = 0.0001$ and $p = 0.0006$, respectively), infants had cranial widths statistically higher than those in their norms. In fact, 30% (13 of 43) of infants had cranial widths at least 2 standard deviations *above* published norms, with a surprising 4.6% of infants having cranial widths that exceeded 3 standard deviations. When evaluated against normative data as published by Farkas,[4] 43% of the infants had cranial widths at least 2 standard deviations above normal, while 9.3% had widths greater than 10 standard deviations *above* normal (Figure 3). Regardless of which normative data is used for comparison, it is evident that the crania of these infant are wider than expected. Indeed, by 8 months of age, more than half (53.5%) of the infants in this study had cranial widths that were within 10 mm of 1 of their parents. More than 11% (11.6%) had widths that were already greater than those of one of their parents (Figure 4).

Cranial Lengths

Infants had an average cranial length of 145.0 mm (SD ±9.4; range, 124 to 166 mm), while fathers and mothers had mean lengths of 196.1 mm (SD ±8.6; range, 174 to 210 mm) and 186.0 mm (SD ±7.1; range, 171 to 207 mm), respectively. ANOVA and

Figure 3. A 5-month old infant with cranial width 3.0 standard deviations above his age- and gender-specific norm.

Figure 4. A 6-month-old infant with a cranial width greater than that of 1 of his parents'. Cranial widths: Father = 145 mm, mother = 132 mm, infant = 133 mm.

subsequent between-group comparison tests indicated that the infants' mean cranial length was statistically smaller than that of the fathers' and mothers' mean lengths ($p<0.05$). The mean lengths of the mothers and fathers were significantly different from each other, but both were appropriate for their age- and gender-specific values (Table 2). Infants' mean cranial lengths fall within published norms except for male infants between 6 and 12 months of age. This group, the largest and most statistically robust, was significantly shorter than published norms (Table 2). In addition, 9.3% of the infants had lengths more than 2 standard deviations *below* normal.

Cephalic Indices

The mean cephalic index for the infants was 88.5 (SD ±8.3; range, 68.1 to 104.8), which was greater than the fathers' mean of 75.1 (SD ±4.41; range, 65.7 to 83.5) and the mothers' mean of 74.2 (SD ±4.34; range, 69.2 to 85.4) (Figure 5). Statistical analysis indicated that the infants' mean cephalic index was statistically greater than both the fathers' and mothers' mean indices ($P > 0.0001$). The mean cephalic indices of the mothers and fathers were not significantly different from each other and were within the normal range. However, mean infant cephalic indices were statistically greater than norms (Table 3). In addition, 14.0% of the infants had a cephalic index greater than 100, indicating that their heads were wider then they were long (Figure 6).

Cranial Circumferences

Infants had an average cranial circumference of 449.1 mm (SD ±16.67; range, 420 to 495 mm), compared to their fathers' and mothers' mean circumferences of 579.6 mm (SD ±17.5; range, 535 to 610 mm) and 553.6 mm (SD ±17.5; range, 520 to 625 mm), respectively. Analysis of variance indicated that the infants' mean circumference was statistically smaller than their fathers' and mothers' ($p<0.0001$). The mean circumferences of the mothers and fathers were significantly different from each other, but both were equivalent to their age- and gender-specific norms. All of the infant age groups had mean circumferences greater than their published norms (Table 4).

Discussion

In 1912, Franz Boas published a groundbreaking study demonstrating the plasticity of the human skull, and that cranial shape and form can change in response to environmental influences.[5,6] From 1908 to 1910, Boas and his team of researchers collected anthropometric measurements on 17,821 immigrants and their children, and showed a statistically significant change in head form

Table 2

COMPARISON BETWEEN THE MEAN CRANIAL LENGTHS COLLECTED IN THIS STUDY AND THE APPROPRIATE AGE- AND GENDER-SPECIFIC NORMS (STUDENT *T* TEST)

Age Range (mo)	Gender	No. of Patients	Mean Cranial Length (SD)	Cranial Length Norm (SD)*	t Value	p Value
0–6	F	2	146.0 (12.7)	133.2 (11.6)	1.509	0.141
	M	5	136.4 (10.0)	135.6 (10.7)	0.158	0.875
6–12	F	3	148.7 (2.8)	149.7 (6.4)	0.265	0.7929
	M	33	145.8 (9.2)	153.7 (9.0)	2.952	0.0048
Adult	F	39	185.9 (7.1)	186.8 (6.8)	0.751	0.4536
	M	39	196.1 (8.6)	197.4 (6.7)	0.962	0.3377

*Infant norms obtained from Hajnis, 1970 and adult norms obtained from Farkas, 1994.

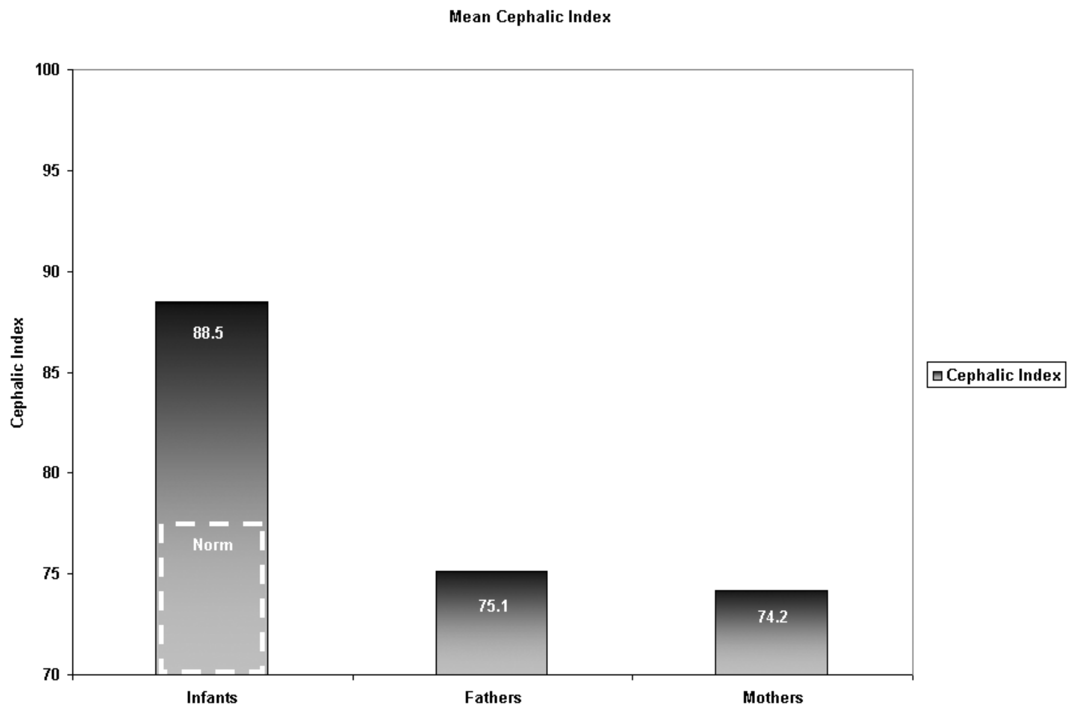

Figure 5. Mean cephalic indices of family members. Mean infant cephalic index was statistically greater than their age- and gender-specific norms (p=0.0000, α=0.05).

Table 3

COMPARISON BETWEEN THE MEAN CEPHALIC INDICES COLLECTED IN THIS STUDY AND THE APPROPRIATE AGE- AND GENDER-SPECIFIC NORMS (STUDENT *T* TEST)

Age Range (mo)	Gender	No. of Patients	Mean Cephalic Index (SD)	Cephalic Index Norm (SD)*	t Value	p Value
0–6	F	2	79.8 (7.9)	73.3 (4.7)	1.590	0.1217
	M	5	97.1 (6.0)	73.7 (5.0)	9.652	0.0001
6–12	F	3	84.7 (2.5)	78.5 (4.5)	2.326	0.0270
	M	33	88.1 (8.2)	78.0 (6.6)	4.487	0.0001

*Infant norms obtained from Hajnis, 1970.

within a single generation of European immigrants. This was considered a landmark study that generated significant controversy because it challenged the widely accepted belief that cranial form was determined exclusively by heredity and race.[7,8]

While at the time, Boas did not understand the specific environmental factors that led to the change in cranial configuration,

Figure 6. A 5-month-old infant with a cephalic index greater than 100. Cephalic indices: father = 78.4, mother = 74.7, infant = 102.3.

today the effect of environment (both intrauterine and postpartum) on the malleable cranium is well established.[9-20] In Europe, in the mid-1800s, the fashion of having infants wear bonnets or bandeaus commonly produced a turricephalic head shape.[21] Distortion of Native American infant skulls from use of cradle boards has also been widely documented, and similar concerns about the overuse of car seats, infant swings, and carriers in contemporary society is now being reported.[21-24]

However, one of the most convincing demonstrations that environment can alter cranial shape is the well-documented increase in deformational plagiocephaly since the introduction of the 'Back To Sleep' campaign in 1992.[25,26] While this was originally reported only in the United States, nearly every other country that has now adopted this recommendation has observed similar increases.[27-29] However, as researchers, what interests us even more, is not so much the increase in the number of infants with the condition, but rather the change in both the type and severity of the deformity now seen in our practices.

Over the past 15 years, we have observed that plagiocephaly has changed from a parallelogram- to a trapezoidal-shaped deformity (Figure 1), likely resulting from the extended time infants now spend on their back. In this study, we concentrated on cranial width and length because of our clinical observations that plagiocephalic heads have become wider and shorter. The cephalic index for all participants was also calculated. This ratio is important because it normalizes the width and length

Table 4

COMPARISON BETWEEN THE MEAN CRANIAL CIRCUMFERENCES COLLECTED IN THIS STUDY AND THE APPROPRIATE AGE- AND GENDER-SPECIFIC NORMS (STUDENT *T* TEST)

Age Range (mo)	Gender	No. of Patients	Mean Cranial Circumference (SD)	Cephalic Cranial Circumference (SD)*	t Value	p Value
0–6	F	2	426.5 (9.2)	360.0 (14.6)	6.309	0.0001
	M	5	435.0 (18.7)	379.5 (15.4)	7.421	0.0001
6–12	F	3	448.7 (1.2)	426.9 (14.6)	2.548	0.0162
	M	33	452.6 (15.6)	437.4 (15.4)	3.340	0.0016
Adult	F	39	553.6 (17.3)	549.0 (14.8)	1.726	0.0857
	M	39	579.6 (17.3)	579.0 (14.4)	0.211	0.8328

*Infant norms obtained from Hajnis, 1970 and adult norms obtained from Farkas, 1994.

measurements, and allows direct comparison between infants of different ages as well as to previously reported normative data. Circumference measurements were also collected because of the observation that many of these infants were no longer falling within the normal ranges on the pediatric percentile growth charts.

Results from this study indicated that these infants' heads are now significantly wider and shorter than their age- and gender-specific norms (Table 1). In fact, 53.5% of the infants had cranial widths approaching 1 of their parents', and despite a mean age of only 8 months in this study, 11.6% had widths that were already greater than 1 of their parents. In addition, many of the infants had heads significantly shorter in length. This increase in cranial width and decrease in length significantly altered the infants' mean cephalic index. The normal width to length ratio varies marginally through the first year, with an index of approximately 73 at birth and 78 between 6 and 12 months of age. After the first year, the cephalic index plateaus at approximately 75 and remains constant through adulthood.[3,4] The infants in this study had a mean cephalic index of 88.5, which was statistically much higher than their age- and gender-specific norms, and statistically greater than their fathers' and mothers' indices (Figure 5). These results demonstrate that, unlike their biologic parents, infants had heads wider and shorter than normal, leading us to believe this alteration in head shape is not genetically induced.

The transformation from the old parallelogram shape to the new trapezoidal shape should be noted by physicians and specialists who diagnose and care for the infant with deformational plagiocephaly. Physicians should also be aware of the change in cranial circumference due to this alteration of head shape. The results of this investigation indicate that the percentile growth curves used for plotting head circumference may not be reliable for this new back sleeping population.

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