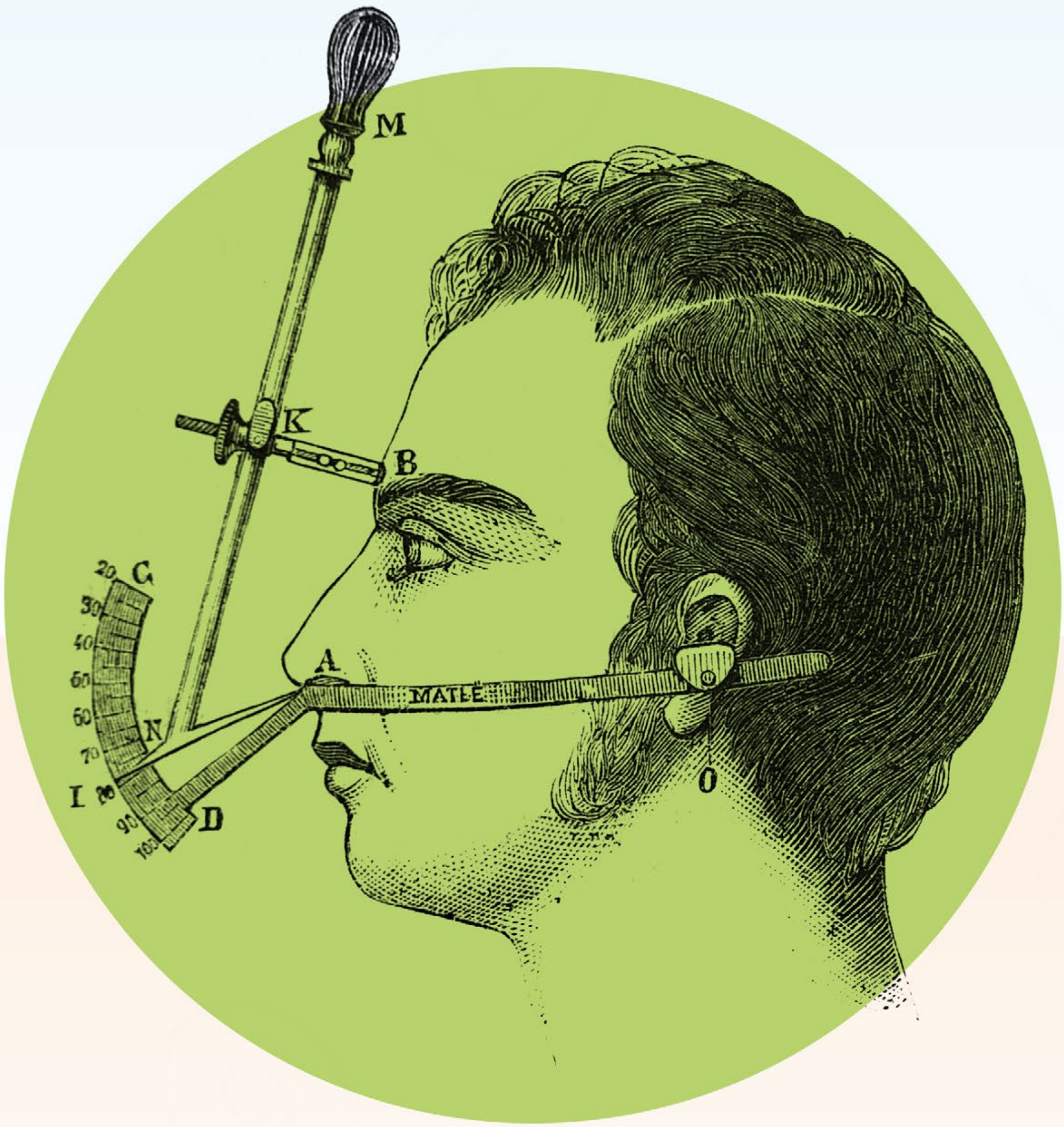
Revisiting the Cephalic Index

The Origin, Purpose and Current Applicability



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Introduction

Cephalometry is the measurement and study of the proportions of the head and face, and infant skull deformities have been the subject of many clinical studies over the last 30 years. Clinical protocols to document change are especially critical during periods of growth and development, but reference values and norms are lacking for infants, especially in the first year after birth. The terms cephalic ratio (CR) and cephalic index (CI) are used interchangeably to denote the ratio of the cranial width to cranial length. The CI calculation of maximum cranial width divided by maximum cranial length has remained constant since the 1840s, although the cranial shape classifications have changed many times over the years.

Anthropometric measures like the cephalic index (CI) are used as criteria for coverage policy by a variety of payer groups. The limitations of using a single two-dimensional linear measure to define the magnitude of a three-dimensional deformity have also been noted by many and will be discussed later. The best clinical use of the CI is as an inexpensive and efficient method to identify infant skull discrepancies and to determine the need for further three-dimensional assessments. The purpose of this paper is to review the historical development of the cephalic index and outline the limitations of using this single measure to define the three-dimensional deformations of infant skulls.

Methods

A literature review was performed to determine the (1) origin of the cephalic index, (2) adaptations of the measure over time, (3) anatomical landmarks and alignments used to obtain the measure, (4) clinical tools used in cranial measurements, (5) necessary considerations for different ethnic, gender and cultural influences, (6) value and limitations of both two-dimensional (2D) and three-dimensional (3D) cranial measurements, and (7) appropriate use of the CI in the documentation of infant skull deformities.

Origin of the Cephalic Index

Anders Adolph Retzius (1796-1860) was an early pioneer of craniometry and is also considered one of the founders of physical anthropology. He is credited with defining the cephalic index to classify human skulls, specifically related to the anthropological findings of prehistoric remains discovered in Scandinavia. He presented this method at the Meeting of Naturalists in Stockholm in 1842 to provide a simple and quick classification of skull shape. The greatest skull breadth was noted to be found immediately behind the temples while the greatest length was from the glabella to the most projecting part of the occipital region. This gave rise to the CI equation of cranial width divided by cranial length and then multiplied by 100 to provide a ratio of the two measurements. It should be noted that no reference was made to skull alignment in any of the three cardinal planes prior to measurement. An arbitrary value of 75% was set as the division between dolicocephalic skulls (CI $< 75\%$) and brachycephalic skulls (CI $> 75\%$). It is important to note that dolichocephaly and brachycephaly were not used to define deformation but were used to merely distinguish differences in overall shape as the original purpose of the cephalic index was to measure skull morphology and not dysmorphology.

Many other early anthropologists contributed to the study of the human skull (e.g., Hermann Welcker (1822-1897), Rudolf Virchow (1821-1902), Pierre Paul Broca (1824-1880), and Thomas Huxley (1825-1895)). Welcker focused on the growth and development of the infant skull; Virchow was one of the first to study craniosynostosis; and Broca developed many new cranial measurement tools. Establishing a normal alignment for the consistent measurement of skulls was a primary focus during this time. Broca, Welcker and Huxley also expanded on the CI classification and introduced new categories and additional subdivisions as shown in Table 1. Still, as early as 1912, Boas noted that the terms brachycephaly and dolichocephaly did not denote a distinct biological type but instead were merely convenient terms used for descriptive purposes. Further, Boas noted that the CI values were arbitrary and designated merely as a means of convenient classification rather than diagnostic limits.

The Frankfurt Craniometric Agreement in 1884 introduced and defined the Frankfurt horizontal plane (FH). Continuing to focus on the precise measurement of the dry skull, the FH was determined by identification of the upper margin of the bony auditory meatus (i.e., porion) and the inferior margin of the orbit on each side of the skull. Connecting the two points on either side determined the horizontal alignment of the skull in space. If any discrepancy (i.e., asymmetry) was noted between the two sides, then the right and left poria and left orbital landmarks would be used for all alignment procedures (Meiyappan, 2015). Another classification of cephalic index as it related to head shape (and not deformation) was also proposed in this agreement and shown in Table 1.

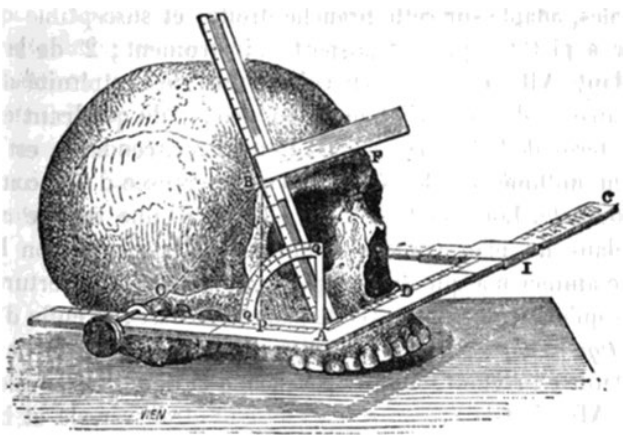
Table 1. *Early cranial index (CI) classifications.*

Retzius' CI Classifications (1840)	Dolichocephalic or long-headed		With cranial index 75 or less	
	Brachycephalic or short-headed		With cranial index above 75	
Broca's CI Classifications (1909)	Dolichocephali		With cranial index 75 or below	
	Subdolichocephali		With cranial index 75.01 to 77.77	
	Mesaticephali		With cranial index 77.78 to 80	
	Subbrachycephali		With cranial index 80.01 to 83.33	
	Brachycephali		With cranial index 83.34 and above	
Frankfurt Craniometric Conference (1884)	Dolichocephalic (long skull)		Below 75.0%	
	Mesocephalic		75.1–79.9%	
	Brachycephalic (short skull)		80.0–85.0%	
	Hyperbrachycephalic		85.1% and over	
Huxley's CI Classifications (1909)	Brachycephaly, round skulls		Index of 80 or upwards	
	(a) Brachistocephali		Index of 85 or upwards	
	(b) Eurycephali		Index below 85, of or above 80	
	Dolichocephali, long skulls		Index below 80	
	(a) Subbrachycephali		Index of 80, of or above 77	
	(b) Orthocephali	Oval skulls	Index below 77, of or above 74	
	(c) Mesocephali		Index below 74, of or above 71	
	Mecistocephali, oblong skulls		Index below 71	
Martin & Saller (1957) Published in Farkas & Munro, 1987			**Males**	**Females**
	Hyperdolichocephal (very long)		≤ 70.9%	≤ 71.9%
	Dolichocephal (long)		71.0–75.9%	72.0–76.9%
	Mesocephal (medial)		76.0–80.9%	77.0–81.9%
	Brachycephal (short)		81.0–85.4%	82.0–86.4%
	Hyperbrachycephal (very short)		85.5–90.9%	86.5–91.9%
	Ultrabrachycephal (extremely short)		≥ 91.0%	≥ 92.0%

Clinical Tools Used in CI Measurements

Serletis & Pait (2016) published a comprehensive review of early craniometric tools. As mentioned, Broca's interest in the human skull led to the development of several of these tools. (Refer to Figure 1. Early craniometric tools.) These early measurement tools laid the foundation for the development of neurosurgical stereotaxis, a method that combines the use of a three-dimensional coordinate system combined with various imaging techniques to locate precise areas deep within the brain.

Figure 1. *Early craniometric tools.*



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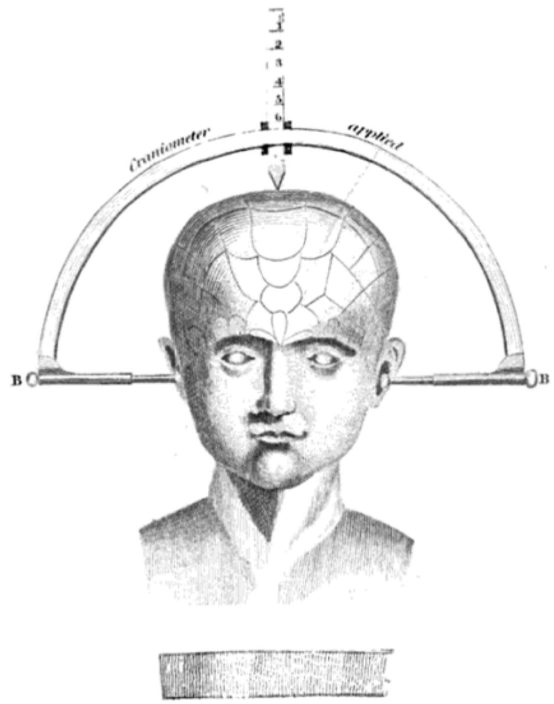

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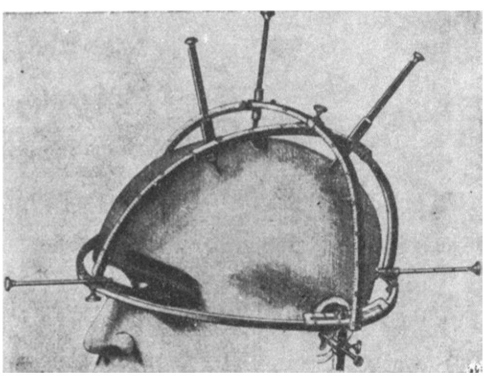

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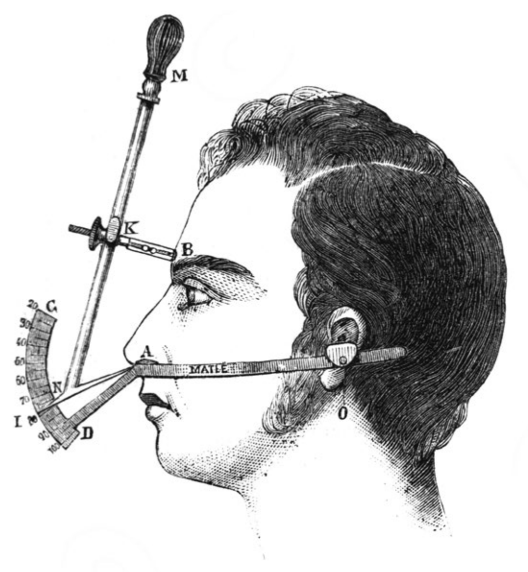

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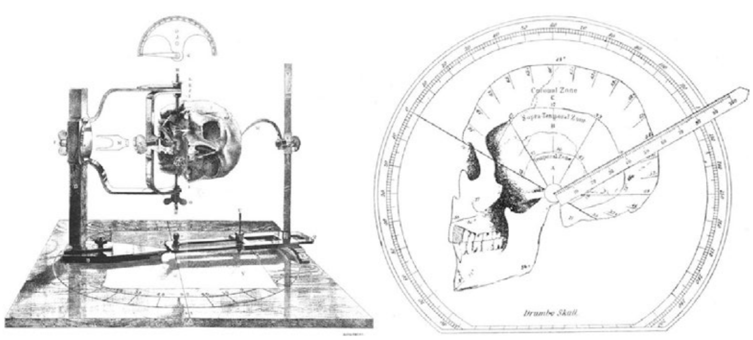

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There are many reference books and publications on the topic of craniometry, including a 1981 publication by Dr. Leslie Farkas on anthropometry of the head and face. This book presents specific methods to meticulously capture craniofacial measurements. These measurements required the development of many unique measurement tools for the purpose of documenting 174 single and paired measurements of the head and face. The population sample of normal, healthy Canadian "children" included 26 groups composed of 50 subjects from six years to 18 years of age. Additional data from 80 young adult subjects were added to the dataset a few years later, and there are more than 100 tables of measurements of healthy young adults in this publication.

An update to the 1981 reference book was published by Farkas & Munro in 1987. This publication presented the cephalic index in three ways: (1) CI modified by Saller (Martin & Saller, 1957), (2) CI from Farkas' data (on six- to 18-year-old subjects), and (3) West German population norms by Hajnis (Hajnis, 1974). To address a younger population, Farkas & Munro "statistically adjusted" the West German norms and were then able to project the curves of the Canadian data below six years of age. Of the 134 infants in this West German data set younger than one year of age, only 47 infants were in the six- to 12-month age range and included 18 male and 29 female infants. It should also be noted that of 11 craniofacial indices, three were acceptable and eight needed further statistical adaptation. Figure 2 shows the original table published in 1987 and is the foundation for many payer coverage policies for brachycephalic and scaphocephalic head shapes. (Figure 2.) It is important to keep in mind that the Caucasian norms between six and 18 years of age were ***collected*** in the early 1970s and the norms for children below six years of age were ***established*** in the 1980s. Without detracting from the enormous contributions made by Dr. Leslie Farkas and others, it is important to understand the limited applicability of the cephalic index norms reported here for use in today's infant populations.

Figure 2. *West German data and cephalic index calculations published in Farkas & Munro (1987).*

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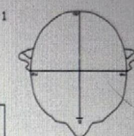
Table 156 Cephalic Index YC-1



Head width (eu-eu) x 100 / Head length (g-op)

Subnormal: head narrow for its length

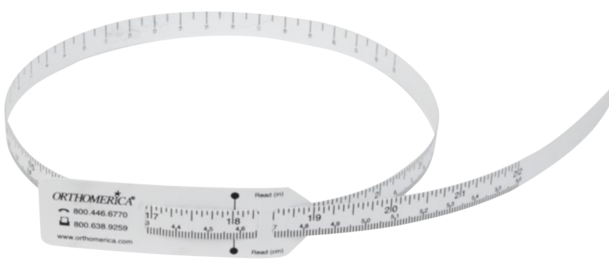
Supernormal: head wide for its length

Age	No.	-2 SD	-1 SD	Mean	SD	+1 SD	+2 SD
Male							
0-15 days	10	70.8	73.8	76.8	3.0	79.8	82.8
16 days-6 months	39	63.7	68.7	73.7	5.0	78.7	83.7
6-12 months	18	64.8	71.4	78.0	6.6	84.6	91.2
1 year	27	66.9	71.8	76.7	4.9	81.6	86.5
2 years	32	67.0	71.8	76.6	4.8	81.4	86.2
3 years	55	68.3	72.4	76.5	4.1	80.6	84.7
4 years	77	68.3	72.6	76.9	4.3	81.2	85.5
5 years	70	68.1	72.5	76.9	4.4	81.3	85.7
Female							
0-15 days	6	72.3	76.3	80.3	4.0	84.3	88.3
16 days-6 months	32	63.9	68.6	73.3	4.7	78.0	82.7
6-12 months	29	69.5	74.0	78.5	4.5	83.0	87.5
1 year	25	67.5	72.6	77.7	5.1	82.8	87.9
2 years	28	65.7	70.4	75.1	4.7	79.8	84.5
3 years	47	70.6	73.8	77.0	3.2	80.2	83.4
4 years	66	67.5	71.9	76.3	4.4	80.7	85.1
5 years	69	68.2	72.5	76.8	4.3	81.1	85.4

In another reference book edited by Farkas in 1994, craniofacial norms for the 2326 healthy Canadian subjects were supplemented by measurements obtained from 208 subjects between birth and three years of age. However, it is clearly noted that the reference to "birth" is actually one year of age due to the difficulty in measuring infants. Shortly afterwards, Kolar & Salter (1997) published a reference book on craniofacial anthropometry that contains exact methods of the identification of appropriate anatomical landmarks and measurement techniques but does not report on any normative data. The contributions from Farkas and others furthered our understanding of anthropometry of the head and face. Use of the Frankfurt horizontal plane (FH) established for adult, dry skulls provided a repeatable reference plane for all measurements from detailed anatomical landmarks. Still, it is important to keep in mind that the subject pools were primarily prone sleepers, the cultural diversity was limited, and the data presented on infants younger than 12 months of age was obtained from a very small group of infants. Interestingly, it is the cephalic index information from the statistically adjusted Hajnis dataset on 134 infants between 0 days and 12 months of age (published by Farkas in 1987) that is most often referenced as the current norm by insurance companies.

Today's craniometric tools consist of manual calipers and measurement tapes along with advanced scanning systems (Figure 3). Cranial calipers and tape measures provide simple, quick, and inexpensive means of gathering and documenting basic parameters of the cranial shape. Circumference, cranial width, cranial length, and transcranial diagonal measurements compared over time provide some insight into the amount of asymmetry and/or disproportion, as well as information about improvement or progression of the deformity. Infants with abnormal head shapes resistant to change with focused repositioning, additional tummy time and/or physical therapy should be referred for a more detailed three-dimensional cranial assessment. There are a variety of clinical scanning systems that capture infant head shapes and provide detailed reports with 2D, 3D and volumetric data. These reports assist the clinician in evaluating the magnitude of asymmetry, disproportion, sloping and displacement of the neurocranium and viscerocranium, and establishing baseline measures for comparisons over time.

Figure 3. *Current craniometric tools.*



Payer Coverage Policies

Many payers continue to reference the Hajnis dataset published by Farkas in 1987 despite its shortcomings that include but are not limited to: (1) only 71 infants were measured between 16 days and six months, (2) only 47 infants were measured between six and 12 months of age (3) a very limited ethnicity is represented, (4) the data collection period relates to prone sleeping infants, and (5) a single linear dimension is used to classify a three-dimensional deformity. Moderate to severe brachycephaly is often defined as a cephalic index that is two standard deviations above the mean. An example of a current coverage policy is shown in Figure 4. Note that the same calculation is used for the cephalic index introduced by Retzius (1842) and that the numerical values come straight from the Farkas publication (1987). However, the number of subjects studied for each age range and the original source of the data is omitted. The number of subjects from the original Hajnis (1974) dataset has been added here in the far right column.

Figure 4. *Example of coverage policy criteria for cranial remolding orthoses.*

Cephalic Index:	Head width (eu-eu) x 100
	Head length (g-op)

Gender	Age	-2SD	-1SD	Mean	+1SD	+2SD	N
Male	16 days–6 months	63.7	68.7	73.7	78.7	83.7	39
	6–12 months	64.8	71.4	78	84.6	91.2	18
Female	16 days–6 months	63.9	68.6	73.3	78	82.7	32
	6–12 months	69.5	74	78.5	83	87.5	29

Anatomical Landmarks and Alignments Used in CI Measurements

More than 179 years later, the calculation of the cephalic index remains the same: (cephalic width / cephalic length) x 100. It is important for clinicians to note the specific landmarks and clinical techniques (e.g., manual or scanned) used by various researchers to obtain and report on cephalic width and length measurements. For example, anterior landmarks reported in various publications include the nasion, glabella, or mid-endocanthion. Posterior landmarks may be the opisthocranion, inion, or at the level of the greatest circumference. Lateral skull landmarks are the most varied and include the eurion, biparietal eminence, posterior to the temporal area, discrete linear distance above otobasion, and other locations. The various landmarks used produce different linear dimensions and make comparison of research outcomes challenging. In many cases, the specific anatomical landmarks used and the vertical location on the head are not clearly described. Further variability is found with the lack of a standardized head alignment, which will also vary the results of the two-dimensional linear measurements.

For these reasons, comparison of measurements between publications is extremely challenging and result in the lack of professional consensus on current clinical craniofacial norms for infants under 12 months of age. When using a particular severity and/or classification scale, it is important that clinical measurements be obtained in as similar a manner as possible relative to the published findings. Table 2 summarizes the many variations found in cephalic index measurements.

Table 2. *Early cranial index (CI) classifications.*

Year	Author(s)	Number of Subjects	Age Range of Subjects	Anterior Landmark	Posterior Landmark	Lateral Landmarks	Standardized Head Alignment / Reference Plane(s)	Clinical Tools
1936	Bayley	31 males and 30 females; white, mostly of North European stock	0–60 months	Nasion	Occipital protuberance	Greatest prominences above external acoustic meatus	Held by assistant	Manual, calipers
1977	Dekaban	1058 Caucasian subjects: 555 males and 503 females	7 days to 20 years of age	2cm above nasion, midline	Most prominent point of the occiput, midline	Greatest transverse diameter in a horizontal plane	Not specified	Manual, calipers
1981	Farkas	654 boys and 658 girls; normal, healthy Canadian children; additional subjects were 80 young adult white males and females (ages not provided)	6 years–18 years	Glabella	Opisthocranion	Eurions	Frankfurt horizontal plane	Manual, calipers
1987	Farkas L & Munro I	1312 healthy Canadian children between 6 years and 18 years; 550 North American young adults; and 630 West German Caucasians (Hajnis data, 1967)	1862 subjects between 6 and 18 years of age; 630 subjects < 6 years of age	Glabella	Opisthocranion	Eurions	Frankfurt horizontal plane	Manual, calipers
2001	Loveday & de Chalain	74 infants	Random sample of infants; not specified	Nasion	Inion	Ears	Not specified	Flexicurve, and tracings
2004	Argenta	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Visual assessment
2004	Hutchison et al.	200 infants recruited at birth		Middle of the nose		Ear markers	Digital photograph of vertex view (i.e., greatest circumference)	HeadsUp measurement technique with elastic band and digital photographs
2005	Graham et al.	193 normal infants	Initial mean age 5.3 months	Not specified	Not specified	Biparietal eminences	Not specified	Calipers
2005	Hutchison et al.	31 case patients and 29 control subjects	Between 2 and 12 months of age	Center of the nose	Widest breadth at right angle to midline	Upper anterior-most point of the attachment of the pinna	Headband applied above the eyebrows and extending around the maximal occipital protuberance	Photo technique and flexicurve
2008	Marcus et al.	Retrospective on available CTs	1–60 months	Nasion	Opisthocranion	Eurions	Alignment via dorsum sella, nasion and vertex	CTs and 3D vector analysis
2009	Hutchison et al.	287 infants	Median age of 22 weeks	Nose	Not specified	Ears	Headband applied above the eyebrows and extending around the maximal occipital protuberance (maximum occipitofrontal circumference–OFC)	HeadsUp measurement technique with elastic band and digital photographs
2010	Koizumi et al.	104 children (62 males and 42 females)	0–3 years of age, 7 age categories: 0–3 months, 4–6 months, 7–9 months, 10–12 months, 1 year, 2 years, 3 years	Not specified	Not specified	Not specified	Not specified	CT scans—landmarks as described by Waitzman et al. 1992
2011	Hutchison et al.	129 children	Mean age of 4 years	Nose	Not specified	Ears	Headband applied above the eyebrows and extending around the maximal occipital protuberance (maximum occipitofrontal circumference–OFC)	HeadsUp measurement technique with elastic band and digital photographs
2011	Wilbrand et al.	30 children	6–8 months of age	Glabella	Opisthocranion	Eurions defined as 1cm above otobasion	Frankfurt horizontal plane; also references subnasion to R/L tragion	Manual calipers
2012	Looman & Flannery	Literature review of multiple publications	Not specified	Glabella (the most prominent point between the eyebrows)	Opisthocranion (most prominent point on the occiput)	Maximum biparietal diameter	Infant should be upright	Manual calipers
2012	Wilbrand et al.	401 children	4 age groups: 0–3 months, 4–6 months, 7–9 months, > 10 months	Glabella	Opisthocranion	Eurions 1cm above otobasion	Frankfurt horizontal plane; also references subnasion to R/L tragion	Manual calipers
2014	Likus et al.	180 healthy Polish infants (83 females and 97 males)	5 age categories: 0–3 months, 4–6 months, 7–12 months, 13–24 months, 25-36 months	Glabella	Most projecting point at the back of the head	Most projecting points at the sides of the head, above and behind the ears	Measurement plane parallel to Frankfurt horizontal plane	CT scans
2014	Meyer-Marcotty et al.	52 Caucasian infants (27 females and 25 males)	6–12 months	Maximum length of measurement plane	Maximum length of measurement plane	Maximum width of measurement plane	0-plane includes nasion and both tragion; measurement plane parallel to 0-plane at maximum posterior curvature	Scan
2016	Dorhage et al.	102 children	4–21 months	Subnasal	Occiput	Sides of midpoint of skull; perpendicular to length	Not specified	3D photogrammetry
2019	Beuriat et al.	Literature review of multiple publications	Not specified	Glabella	Opisthocranion	Maximum bi-parietal length	Not specified	Not specified
2020	Choi et al.	207 infants	3–14 months	Occipitofrontal diameter	Occipitofrontal diameter	Biparietal diameter	Not specified	3D scan
2020	Wang et al.	4456 term Chinese infants	Up to 6 months of age	Glabella	Opisthocranion	1cm higher than attachment point of both ears	Wilbrand's et al. standardization scheme	Manual calipers
2021	Phelan et al.	870 patients	5 age groups: 0–3 months, 3–6 months, 9–12 months, 2-3 years, 12-14 years	Glabella	Most projecting point of the occipital skull	Biparietal diameter was most projecting points of the parietal skull	Farkas method; Frankfurt horizontal plane	Manual calipers

CI Severity Scales

More recent publications suggest that the cranial index has risen to 80-85% (Meyer-Marcotty, et al. 2014). Still, the definition of deformational brachycephaly has not yet been standardized and is reported with a wide range of CI values between 80% and 97% (Graham et al., 2020). Phelan et al. (2021) recently suggested that cephalic index values between 82-86% represent a cosmetically acceptable range of infant skull proportion. Table 3 outlines the wide range of severity scales used to classify the disproportion of infant head shapes over the last 10 years. Again, any of these severity scales may be selected for clinical use if the clinical measurements align with the procedures detailed in the publication. (A more detailed table representing publications from 1936 to 2021 is provided as Appendix A.)

Table 3. *Examples of CI severity scales reported in the medical literature.*

2020—Choi et al.	
Brachycephaly	
Mild	88 – 90%
Moderate	90 – 93%
Severe	> 93%
Very Severe	> 96%

2020—Graham et al.	
Brachycephaly	
Normal	< 90%
Mild	90 – 93%
Moderate	93 – 97%
Severe	> 97%

2018—Kelly et al.	
Brachycephaly	
Normal	< 88%
Mild	88 – 90%
Moderate	90 – 93%
Severe	> 93%

2015—Lin et al.	
Brachycephaly	
Mild	82 – 90%
Moderate	90 – 100%
Severe	> 100%

2012—Looman & Flannery	
Brachycephaly	
Mild	82 – 90%
Moderate	90 – 100%
Severe	> 100%

2020—Wang	
Brachycephaly	
Mild	91 – 95%
Moderate	95 – 99%
Severe	> 99%
Scaphocephaly	
Mild	79 – 82%
Moderate	76 – 79%
Severe	< 76%

Phelan et al. (2021) identified a durable change in craniofacial norms since the CI charts that were first published in the 1980s. They note that CI norms have increased and suggest that CI averages range between 82–86% and are within a cosmetically acceptable range of "normal." Figure 5A shows drawings of the cephalic index changes from the Phelan article. However, this depiction is inaccurate as the length was maintained and only the width was increased to account for the change in proportion from 75% to 85%. Figure 5B shows a more realistic change in head shape as the cranial length decreases concurrently with the increase in cranial width. The resultant head shape in Figure 5B is more commonly seen in today's cranial clinics.

Figure 5A. *Changes to cephalic index as shown in Phelan et al. (2021).*

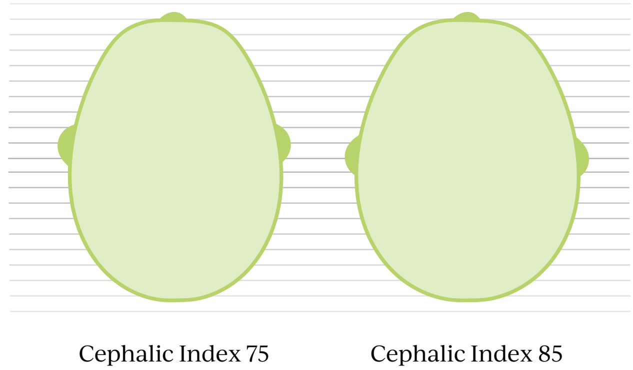
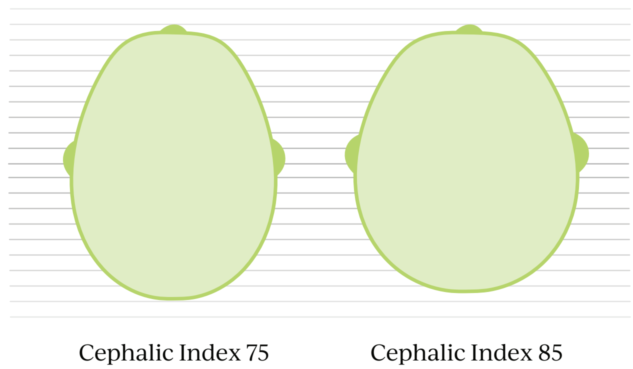


Figure 5B. *Modified changes to cephalic index to show a concurrent decrease in cranial length with the increase in cranial width.*



As a result of these discrepancies, Orthomerica was prompted to assess the cephalic index for CRO scan submissions diagnosed with various head shape deformities. In approximately 9000 submissions, the CI and associated diagnosis reported by clinicians were:

- Deformational scaphocephaly 63–85%
- Deformational asymmetrical scaphocephaly 69–82%
- Deformational plagiocephaly 71–108%
- Deformational brachycephaly 84–111%
- Deformational asymmetrical brachycephaly 83–110%

This data represents the independent clinical perspectives of cranial clinicians from around the world and further reinforces the need to establish a professional consensus for both clinical diagnoses and treatment recommendations.

Limitations of the Cephalic Index

Perhaps the biggest limitation of the use of the cephalic index for today's cranial population is in the linear nature of the cranial width divided by the cranial length. A single two-dimensional measurement fails to capture the three-dimensional deviations of infant skull deformities. Many different authors have identified the value of the CI when used for specific purposes as well as the limitations in generalizing this measure across ages, genders, ethnicities and diagnoses. Limitations to the use of the cephalic index are summarized in Table 4.

Table 4. *Cephalic index limitations.*

Year	Author(s)	Limitations of CI
1936	Bayley	• Innate differences in rates of growth of different parts of the body • CI increases rapidly from 1-7 months, remains at an approximately constant level until ten months, and then decreases
1977	Dekaban	• CI gives the numerical value of the interrelationship between head breadth and length • In persons whose head shape is greatly abnormal, cranial volume is of greater value than individual measurements in assessing the size of the brain
1981	Farkas	• Sources of error: improper identification of landmarks; problems with measuring tools; improper measuring technique; head position (e.g., FH); vertical orientation of facial profile (seen with facial asymmetry)
1987	Farkas & Munro	• An index gives information about the relative sizes of parts of the human body and to some extent about their shape (but not necessarily about their contours) • No detailed anthropometric data of the face are available for North American Caucasian children less than 6 years old; therefore, West German population norms have been used (from Hajnis, 1972)
2001	Loveday & de Chalain	• Brachycephaly was defined arbitrarily as CI greater or equal to 85% (i.e., a broad head)
2005	Hutchison et al.	• It has been shown that supine sleeping infants do develop a wider head shape than those who sleep in the prone or lateral positions (Huang et al., 1995) • It may be necessary to redefine normal cephalic indices for children in countries where the supine sleep position has been adopted • The true definition of a "normal" head shape would require a large study using different ethnic groups and recording the predominant sleeping positions used • There is a need for further work to establish age-specific norms for cephalic index • The true nature and severity of the deformity may not always be obvious in the vertex view • A CI of 93% or greater is conservative, but can be qualitatively supported based on clinical experience
2008	Marcus et al.	• Complete 3D skull morphology is far more complex than can be represented by any single measure of the collective interpretation of several measurements • CI considers only length and width, failing to characterize any other dysmorphology or correction • A rectangle and ellipse are entirely different, but could potentially share the same width-length ratios • CI does not demonstrate widely varying patterns of frontal bossing, occipital bossing, bitemporal narrowing and/or vertex height deficiency • CI is a relative index with no predefined reference origin (zero point); therefore, CI cannot distinguish regional differences such as frontal and occipital bossing • The technique used for measuring CI varies widely • As a single parameter, the CI does not confer understanding of regional severity or specificity • No methods have been described to quantify or objectively measure frontal bossing, midline ridging and occipital protuberance • 3D vector analysis was developed to address inadequacies of current cranial anthropometric techniques; it captures the significant findings that differentiate diagnoses, and it captures the subtle variations of individuals with the same diagnosis • Cranial dysmorphology defined by simplistic parameters • Substantiation of a "surgical technique" to provide normalization of head shape for any form of dysmorphology requires objective analytic methodology

Year	Author(s)	Limitations of CI
2009	Hutchison et al.	• Acknowledge lack of standardization of measurement technique in assessing infant head shape • 3D scanning systems will eventually provide better standardization of head shape measurement
2010	Koizumi et al.	• CI is reported to have racial and geographical variations • Cohen's CI classification could not be adapted for Japanese children with normal brain development because almost all would be classified as hyperbrachycephalic • Secular changes of human skull shape showed a tendency to be brachycephalic, and this brachycephalization has occurred in various races all over the world • Because there are regional and racial differences in craniofacial morphology, surgical planning for craniosynostosis should be based on the appropriate racial cephalic index
2011	Hutchison et al.	• There is a need for a large population-based study to establish CI norms for Western supine-sleeping populations from infancy through childhood • A limitation of this study is the two-dimensional nature of HeadsUp measurements in what is essentially a three-dimensional problem
2011	Wilbrand et al.	• Skeletal landmarks in infant heads may be more difficult to find than in adult skulls • Skeletal landmarks must sometimes be difficult to identify in severely deformed heads • Lack of a bony landmark in the occipital area
2012	Looman & Flannery	• Published CI norms for age and gender which were established in the 1970s • Published reports of severity classification systems using these measurements vary widely, and standards remain to be established across disciplines
2013	Franco et al.	• Terminology standardization is essential to facilitate communication among professionals, enabling comparisons to be made between different studies and affording increasingly evidence-based outcomes
2013	Shweikeh et al.	• Must factor in the role of heredity along with environment
2014	Meyer-Marcotty et al.	• In the 1970s, a CI of 76.7% in infants at 12 months of age was reported (Dekaban, 1977) • More recent publications suggest the CI has risen to 80-85% since 1992 (Graham et al. 2005; Hutchison et al. 2004; Kane et al. 1996) • The ideal head shape is not yet known • Data prior to 6 months not analyzed due to the weak neuromotorical development as well as the poor head control in the first months of life
2020	Graham et al.	• Brachycephaly has been defined as CI >/= 80%, >/= 82%, >/= 93%, 95–104%, and >/= 97% • No established validated brachycephaly or asymmetrical brachycephaly scale
2020	Phelan et al.	• Current norms were established by a small sample of white children in the 1987 Farkas and Munro data set • The sample size of the Farkas and Munro data set within the critical age range of 0–6 months is small, with a total sample size of only 38 girls and 49 boys, and all these children were West German and of Caucasian ethnicity • The mean cephalic index has changed • Data suggest that since the 1980s, a durable change in craniofacial norms has occurred • Cephalic index values between 82–85% demarcate the new craniofacial norm and exist within a cosmetically acceptable range • Cephalic index norms have increased since the 1980s

The Value of 2D and 3D Measurements to Document and Classify Skull Shapes and Deformities

The overlap in the CI ranges further reinforces the need to establish a standard classification for the cephalic index as one component of the overall head shape. It is also important to keep the limitations of the CI in mind. For example, two distinct shapes such as a rectangle and an ellipse could have the same width and length measurements, as shown in Figure 6. Also, without a zero or reference point, the CI does not indicate specific components of the head deformity, such as forehead bossing or flattening, occipital flattening, or parietal involvement. Figure 7 shows two infant head scans that have an almost identical CI but are clearly different in shape. Frontal involvement may evolve as either flattened or bossed, as shown in Figure 8, and parietal involvement also differs between head shapes, as shown in Figure 9. Clearly, the CI does not capture or report on these significant head shape differences.

Figure 6. *An ellipse and a rectangle have the same length and width dimensions.*

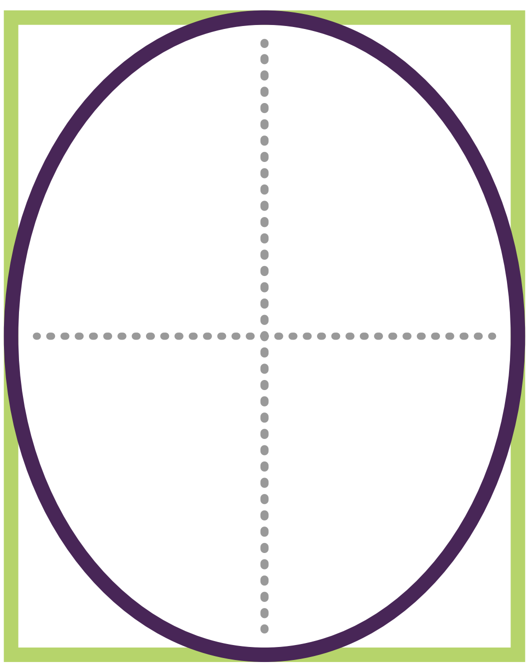


Figure 7. *Different infant head scans with similar cephalic index measurements.*

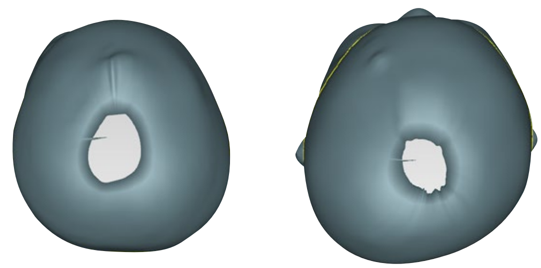


Figure 8. *Deformational brachycephaly may result in either frontal flattening or bossing.*

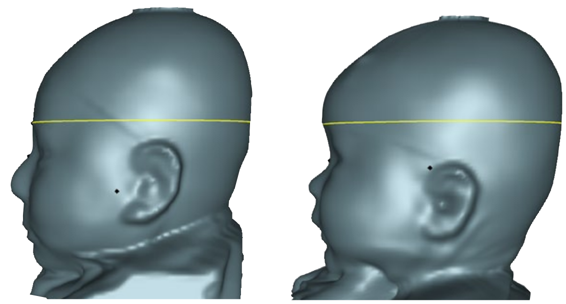
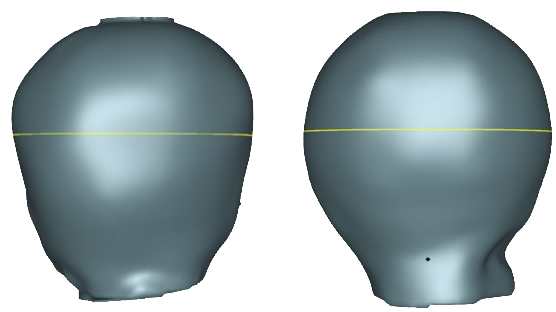


Figure 9. *Posterior views of different head shapes and varied involvement of the parietal regions.*



Graham et al. (2020) provides support for the complexity of infant head shapes and the need for more than a singular linear measurement to quantify severity. This study looked at 500 infants with deformational asymmetrical brachycephaly (DAB) and used both the CI and Children's Healthcare of Atlanta (CHOA) Plagiocephaly Severity Scale (i.e., CVAI) to classify infant skull deformities. While both these measures are still two-dimensional in nature, the concept of combining multiple measures to more accurately document surface and shape changes and to classify severity of three-dimensional head deformities should be noted. (Refer to Figure 10.)

Conclusion

The commonly accepted cephalic index (CI) chart includes columns for gender, age, mean, and two standard deviations above and below the mean. These measurements were obtained more than 50 years ago from prone sleepers, and further investigation reveals the limited applicability of these reference charts due to the very small number of subjects measured and limited ethnic background of the subjects. The CI provides information about only one of the most obvious features of the dysmorphology, specifically the amount of disproportion. Without a reference point the CI does not specify other distinct features such as frontal flattening or bossing, parietal shape or involvement, sloping, and/or posterior asymmetry.

For today's cranial clinicians, the commonly referenced cephalic index chart fails to reflect (1) the natural skull changes noted with supine sleeping infants, and (2) the cultural diversity of the infant population currently treated. Used in isolation, the two-dimensional and linear nature of the CI fails to describe the magnitude of the three-dimensional head deformity. However, the CI can and should be used in conjunction with other two- and three-dimensional measurements to provide a more detailed description and understanding of the entire cranial deformity. The limitations of using the CI in isolation have been outlined here. The CI results should be discussed with the medical team along with a complete review of other two- and three-dimensional anthropometric measurements obtained from the scan report.

Figure 10. *An example of combining the CI and CHOA Plagiocephaly Severity Scale for assessing deformational asymmetrical brachycephaly.*

Table 1. Number of infants within each cranial severity category at the start of treatment based on the initial cranial vault asymmetry index (CVAI) and cephalic index (CI).

		Cranial Index (CI) Scale Severity				
		Normal CI < 90%	**Mild 90% ≤ CI ≤ 93%**	**Moderate 93% < CI ≤ 97%**	**Severe CI > 97%**	**Total**
Children's Healthcare of Atlanta (CHOA) Scale Severity	Normal CVAI < 3.5	N/A	N/A	N/A	N/A	N/A
	Mild 3.5 ≤ CVAI < 6.25	N/A	59	97	54	210
	Moderate 6.25 ≤ CVAI < 8.75	N/A	86	78	40	204
	Severe 8.75 ≤ CVAI < 11	N/A	34	23	10	67
	Very Severe CVAI ≥ 11	N/A	9	7	3	19
	Total	N/A	188	205	107	500

Taken from Graham et al. (2020). Significant factors in cranial remolding orthotic treatment of asymmetrical brachycephaly. J Clin Med, 9(4):1027.

Appendix

Proposed CI Classifications Before and After the Back to Sleep Program.

Data collected and assessed **BEFORE** the AAP's supine sleeping recommendations

Year	Author(s)	Proposed CI Classifications	CI Cut-Off for Norms	Additional Notes
1936	Bayley	Not specified	Not specified	Multiple tables for means and SDs provided for boys and girls from 1-12 months of age, and at 15, 18, 24, 30, 36, 48 and 60 months of age
1977	Dekaban	Various degrees of brachycephaly are associated with a CI greater by 5–20% than the overall mean of 77.9% for males or 78.4% for females	Various degrees of brachycephaly for males = 81.8–93.5% Various degrees of brachycephaly for females = 82.3–94.1%	77.9% for males 78.4% for females
1981	Farkas	Not specified	Not specified	Mean index value represents the average proportion between the related measurements. SD quantifies the normal differences between the index values of the members of the samples; thus, the normal range is from 2 SD below to 2 SD above the mean
1987	Farkas & Munro	Not specified	**Male** 16 days–6 months • Mean 73.7% / SD 5.0 • -2SD 63.7 • +2SD 83.7 6–12 months • Mean 78.0% / SD 6.6 • -2SD 64.8 • +2SD 91.2 **Female** 16 days–6 months • Mean 73.3% / SD 4.7 • -2SD 63.9 • +2SD 82.7 6–12 months • Mean 78.5% / SD 4.5 • -2SD 69.5 • +2SD 87.5	Table 1. Cephalic index—provides means and SDs for males and females ages 6 years to 18 years. Table 156. Cephalic index—provides means and SDs for males and females ages 0 days to 5 years (Hajnis data, 134 subjects from 0 days to 12 months)

Data collected and assessed **AFTER** the AAP's supine sleeping recommendations

Year	Author(s)	Proposed CI Classifications	CI Cut-Off for Norms	Additional Notes
2001	Loveday & de Chalain	Brachycephaly was arbitrarily defined as CI > 85%	Normal CI range is 75–85%	N/A
2004	Argenta	Classification based on clinical observation alone; brachycephaly scale of 1 to 3	**Grade 1** = central posterior deformity **Grade 2** = central posterior deformity, widening of posterior skull **Grade 3** = central posterior deformity, widening of posterior skull, vertical head, head growth, or temporal bossing	N/A
2004	Hutchison et al.	Not specified	Cases identified when the CI was ≧ 93%	N/A

Data collected and assessed **AFTER** the AAP's supine sleeping recommendations

Year	Author(s)	Proposed CI Classifications	CI Cut-Off for Norms	Additional Notes
2005	Graham et al.	By definition, brachycephaly has CI > 81%	Current normative CI is 86–88%	N/A
2005	Hutchison et al.	Normal head shape is OCLR < 106% and < CI 93% A value below 70% indicates an extremely narrow head and a value of 100% indicates a head that is as wide as it is long	Cases when the CI was ≧ 93% No consistent cutoff point in the literature defining brachycephaly	N/A
2009	Hutchison et al.	Normal head shape is OCLR < 106% and < CI 93%	CI < 93%	N/A
2010	Koizumi et al.	**CI classification for Japanese infants:** Dolichocephaly = 79.1% or less Mesocephaly = 79.2% to 93.8% Brachycephaly = 93.9% to 101.1% Hyperbrachycephaly = 101.2% or higher **Cohen classification (2000):** Dolichocephaly = 75.9% or less Mesocephaly = 76% to 80.9% Brachycephaly = 81% to 85.4% Hyperbrachycephaly = 85.5% or higher	Brachycephaly 93.9–101.1%; hyperbrachycephaly 101.2% or higher	Mean CI for Japanese children with normal brain development was 86.5
2011	Hutchison et al.	Not specified	CI >/= 93% is considered outside the normal range and indicates brachycephaly or short wide head shape with central occipital flattening	N/A
2011	Rogers	CI is historically 75-80% in North America, although some observers suggest that the normal CI has risen to 80-85% in response to supine sleeping	N/A	N/A
2012	Looman & Flannery	Mild: CI = 82-90% Moderate: CI = 90-100% Severe: CI = > 100%	Normative CI for healthy infants was 86-88% (Graham et al., 2005) Schoolchildren in Japan and Korea are reported to have a CI in the range of 85-91% (Graham et al., 2005) Infants in Nigeria have a CI range of 75-78% (prone sleepers) (Graham et al., 2005) Prone sleepers in the US had a mean CI of 78% (Dekaban, 1977)	Cranial length measured in same plane as maximum circumference Cranial width is greatest transverse diameter of the head on a horizontal plane

Data collected and assessed **AFTER** the AAP's supine sleeping recommendations

Year	Author(s)	Proposed CI Classifications	CI Cut-Off for Norms	Additional Notes
2012	Wilbrand et al.	75th percentile is mild 90th percentile is moderate 97th percentile is severe	**Male** 0-3 months • 75th = 85.7% • 90th = 91.8% • 97th = 98.4% 4-6 months • 75th = 87% • 90th = 93% • 97th = 95.9% 7-9 months • 75th = 87% • 90th = 91.4% • 97th = 96.6% 10-12 months • 75th = 86.5% • 90th = 92.1% • 97th = 97% **Female** 0-3 months • 75th = 85.4% • 90th = 87.2% • 97th = 90.3% 4-6 months • 75th = 86.6% • 90th = 92.9% • 97th = 99.8% 7-9 months • 75th = 82.9% • 90th = 89% • 97th = 90.0% 10-12 months • 75th = 85.9% • 90th = 89.5% • 97th = 94.8%	Considered age, gender, and percentiles
2013	Franco et al.	Ultradolichocephalic x–64.9% Hyperdolichocephalic 65.0–69.9% Dolichocephalic 70.0–74.9% Mesocephalic 75.0–79.9% Brachycephalic 80.0–84.9% Hyperbrachycephalic 85.0–89.9% Ultrabrachycephalic 90.0%–x	N/A	N/A
2013	Shweikeh et al.	N/A	N/A	Infant cephalic index in the US has seen a corresponding change from a mean of 78% in the 1970s to a range of 86-88% in the 2000s
2014	Likus et al.	**CI values:** < 3 months = 80.19% 4-6 months = 81.45% 7-12 months = 83.15% < 2 years = 81.05% < 3 years = 79.76%	**Cohen and Maclean classification:** Dolichocephaly up to 75.9% Mesocephaly 76.0–80.9% Brachycephaly 81.0–85.4% Hyperbrachycephaly > 85.5%	Mean value of CI for Polish children with normal development of brain is 81.45%
2014	Meyer-Marcotty et al.	N/A	Normal CI 80–85% reported in the literature; supported by this study where CI was 81.76% at 12 months of age	N/A
2014	Musa et al.	Dolichocephaly = < 74.9% Mesocephalic = 75–79.9% Brachycephaly = 80–84.95% Hyperbrachycephalic = > 85%	N/A	N/A
2015	Lin et al.	Mild = 82-90%, with no posterior widening of the skull Moderate = 90-100%, with posterior widening of the skull Severe = > 100%, with a vertical head shape or temporal bossing	N/A	N/A
2016	Dorhage et al.	Brachycephaly is > 85%	75-85% is normal	N/A
2019	Beuriat et al.	Mild 82–90% Moderate 90–100% Severe > 100%	N/A	N/A
2019	Cevik et al.	N/A	Asymmetrical brachycephaly = CVAI > 7% and CR ≥ 94%	N/A

Data collected and assessed **AFTER** the AAP's supine sleeping recommendations

Year	Author(s)	Proposed CI Classifications	CI Cut-Off for Norms	Additional Notes
2020	Choi	Mild = 88–90% Moderate = 90–93% Severe = > 93% Very Severe > 96%	CI > 90%	N/A
2020	Graham et al.	**CI:** Mild 75th percentile Moderate 90th percentile Severe 97th percentile (Wilbrand classification)	Normal ranges are usually reported between 75-85%	N/A
2020	Wang et al.	**Standard:** Mild 82-80% Moderate 90-100% Severe > 100% **Chinese infants:** Mild 91-95% Moderate 95-99% Severe > 99%	CI ≥ 91% indicates brachycephaly CI ≤ 82% indicates dolichocephaly	N/A
2021	Phelan et al.	Not specified	Cephalic index values between 82–85% new norms	Mean CI 85.4% for girls Mean CI 85.4% for boys

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