Cranial index of symmetry: an objective semiautomated measure of plagiocephaly

Technical note

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Object. The prevalence of deformational, or positional, plagiocephaly has increased during the last decade. Treatments vary among centers, ranging from expectant management to orthotic helmet therapy to craniofacial remodeling. This management variability is partially due to a lack of objective methods with which to measure the severity of plagiocephaly, as well as procedures that are not cumbersome or require radiographic studies. A simple and objective method of determining the degree of cranial deformation has been developed.

Methods. A headband placed around the head was marked with two adjustable points—one denoting the nasion and the other, the inion. A digital camera was used to image the head from a vertex view. The shape of the headband and the area of each hemisphere were then determined by analyzing the image on a personal computer in a semiautomated fashion. A cranial index of symmetry (CIS) was calculated and, by definition, equaled 100% for a perfectly symmetrical head. In this preliminary study, the authors studied eight children referred for evaluation of their plagiocephaly and eight infants referred for other reasons.

In the unaffected infants the mean CIS was $96.3 \pm 1.3\%$ (standard deviation). In children with clinical evidence of plagiocephaly, however, the CIS was $81.9 \pm 3.4\%$ ($p < 0.001$). Although the CIS in healthy children was never less than $95\%$, that in all infants with plagiocephaly was below $90\%$.

Conclusions. Although preliminary, this objective nonradiographic measurement of cranial symmetry appears to allow grading of the severity of positional plagiocephaly. The aforementioned methodology may potentially be used as an unbiased means of comparing different treatment modalities in longitudinal studies.

KEY WORDS • cranial symmetry • plagiocephaly • craniofacial remodeling • orthotic helmet • pediatric neurosurgery

Clinical Material and Methods

Patient Population

Sixteen infants who ranged in age between 2 and 10 months were included in this study. Eight children were referred for cranial dysmorphism consistent with plagiocephaly, whereas eight were referred for other reasons and served as controls.

Measurement Technique

A white high-contrast elastic headband (Nike, Beaverton, OR) was placed around an infant’s head in a similar manner and location as those used when routinely determining head circumference. The headband compressed the hair against the scalp, minimizing its effects on the overall head shape. Two small black spots, which were made by an indelible marker on opposite ends of the headband, denoted the location of the nasion and inion. These markings were manually adjusted when positioning the elastic headband and served to identify the midline. A
standard digital camera was used (Nikon USA, Melville, NY) to obtain a digital photograph viewed from a point perpendicular to the axial plane of the headband. The entire outline of the headband had to be visualized on the image to minimize parallax errors. The image, captured in a commonly used imaging compression format (that is, a JPEG), was downloaded to an Intel-based personal computer (Intel Corp., Santa Clara, CA) running the Windows 98 operating system (Microsoft, Redmond, WA). Commercially available Matlab technical computing software with the Image Analysis Toolbox (Mathworks, Natick, MA) provided the software analysis environment. The software greatly facilitates matrix manipulations, including those specific for image analysis. A brief semiautomated subroutine written inhouse specifically for this purpose was then used for image analysis. First, contours were automatically drawn for a typical threshold level (range 0–255) (Fig. 1A). If one of the contours was not adequately tracing either the inner or outer margins of the headband, a new threshold was manually chosen and the process repeated (Fig. 1B). Once this iterative process was optimized, the contour outlining the headband was chosen (Fig. 1C). Additionally, the nasion and inion denoted by the black spots on the headband were chosen (Fig. 1D). The remainder of the analysis was automated and consisted of calculating the area of each hemisphere that was encoded by the number of pixels (Fig. 1E). Furthermore, the area of hemispheric overlap was calculated by inverting one of the two hemispheres onto the other by using the midline as the axis (Fig. 1F and G). The area of overlap (Fig. 1H) was then doubled and divided by the total area to yield the CIS, expressed as a percentage. A perfectly symmetrical head would, therefore, yield a CIS of 100% because twice the overlap area is equal to the total area. Typical computer running time was less than 2 minutes including displays of automatic graphic and numeric results.

The child depicted in Fig. 1 was referred for evaluation of a left extraaxial collection, and the CIS was found to be 91.7%. A magnetic resonance image, obtained at approximately the same axial level where the headband was placed, was used for additional technique verification (Fig. 2). A single iteration was required to determine the appropriate threshold for the external outline of the hyperintense scalp. The midline was chosen as the anterior and posterior margins of the interhemispheric fissure. A CIS of 91.2% was calculated.

Results

The mean CIS in the control group was 96.3 ± 1.2% (± standard deviation), whereas that in patients with plagiocephaly was 81.9 ± 3.4%. A statistically significant difference between the two groups was found (Student t-test, p < 0.001). In this cohort of patients, the CIS in infants with plagiocephaly never exceeded 85%. Correspondingly, the CIS in all control patients was greater than 90% (Fig. 3).

Discussion

Occipital, or positional, plagiocephaly has become one of the most common reasons for referral to a pediatric neurosurgeon. In an effort to reduce the incidence of sudden infant death syndrome, the American Association of Pediatrics has recommended that infants be placed supine. This, in turn, appears to have increased the incidence of positional plagiocephaly. This deformity, however, can also be caused by a true unilateral synostosis of either the lambdoid or coronal sutures. True synostosis, fortunately, occurs in less than 5% of cases. The natural history of positional plagiocephaly is unclear. Because skull
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growth is maximal during the 1st year of life, the deformity is “outgrown” as the child becomes more active. This is evidenced by the fact that the number of adults with appreciable cranial asymmetry is far less than that in the neonatal population. Treatment options range from expectant management to helmet therapy to craniofacial surgery. The associated risks and costs, obviously, vary greatly. The cost of helmet therapy, for example, can range from $500 to $3500.

The major difficulty in establishing treatment guidelines for this condition has been the lack of an objective, convenient method for grading the severity of cranial deformation. Although various retrospective outcome measures have been used, all have had significant drawbacks. Parental satisfaction, although obviously essential in the overall outcome of treatment, is a subjective measure. Computerized tomography scanning introduces the possible risks of radiation and/or sedation. Simplistic orthogonal skull measurements involving calipers, for example, are cumbersome. In other methods the entire shape of the head is not taken into account. Rather, linear distances between the midline and outer table of the skull at predefined intervals are obtained bilaterally, yielding an incomplete measurement of cranial dysmorphism. We believe our method is objective, fully reflects the planar contour of the head, and yet avoids sedation or exposure to radiation. In addition, data collection can be performed by anyone capable of using a standard digital camera. The procedure requires a financial expenditure of approximately $2000 for the computer hardware, software, elastic headband, and digital camera, which is on par with the cost of a single helmet. The majority of pediatric neurosurgeons practicing in the US already own, or have access to, a personal computer and a digital camera. The entire process requires less than 10 minutes to perform.

The semiautomated technique relies on a high-contrast elastic headband, which can be purchased in any sporting goods store. The headband compresses the hair and serves as a reliable means of outlining the shape of the head, similar to obtaining a head circumference measurement. The elastic nature of the headband not only aids in fitting infants with a wide range of head circumferences, but also allows for the two markings to be maneuvered over the nasion and inion. To obtain an accurate axial shape of the head, it is imperative that parallax be minimized. Thus, the ideal photographic line-of-sight would be perpendicular to the plane of the headband. This is accomplished by ensuring that the thin (< 5-mm) headband is visible all around the perimeter of the infant’s head on the final image. The actual distance of the camera to the patient affects only the magnification, which is not a factor in calculating the CIS. The shape of the headband and the ratio of one hemispheric area to its contralateral hemisphere remain constant. The white color of the high-contrast headband facilitates its recognition by the automated computer because the contour detection algorithm relies on contrast differences to draw shapes of items within the digital image. The user must contend with the program only twice: first, to choose a contour level between 0 and 255 that best selects either the inner or outer outline of the headband; second, to mark the nasion and inion depicted by the dark spot on the headband. Contour selection is an iterative process, although a mean of five to six levels are chosen for a particular CIS analysis. In the rare instances when the automated algorithm is having difficulty in detecting the appropriate contour, standard image-editing software can be used to enhance the image prior to processing. In addition, in instances in which a digital camera is unavailable, an ordinary photograph can be obtained.

**Fig. 2.** A: Axial magnetic resonance image obtained in same child depicted in Fig. 1. B: The initial computer-generated contour was deemed sufficient. C: The appropriate contour was selected and the midline was marked by selecting the anterior and posterior margins of the interhemispheric fissure. D: After appropriate matrix inversion and rotation, the area of overlap is calculated. The CIS was 91.2%.

**Fig. 3.** Bar graph showing the CIS obtained in eight patients with plagiocephaly (red) and eight control patients (blue). Although the CIS is a continuum, in our cohort a CIS greater than 85% was not observed in any patient with plagiocephaly. Conversely, a CIS less than 90% was demonstrated in all control patients with plagiocephaly (dashed yellow lines denoting this border zone).
and later digitized on an optical scanner. The processing can then continue similar to that involving a primary digital image.

Although this study is preliminary, our findings demonstrate that this objective measure of cranial deformation is capable of numerically grading cranial symmetry. Because the definition of “normal” and “plagiocephalic” is in itself a subjective distinction, an individual CIS score has little value. The CIS, however, can be invaluable in monitoring results of treatment as well as objectively comparing the severity of one child’s cranial deformation with that of another. Current and future studies should be designed to investigate the variance of the CIS obtained by various personnel. Furthermore, longitudinal studies to determine the rate of deformational improvement for individual infants, as well as a comparison of results to a physician/parental grading scale, will also be performed. Taking full advantage of the Internet revolution, a web-based database allowing physicians and parents to submit digital images of infants with cranial deformation for calculation of CIS is being planned. These images can already be transferred as a standard electronic mail attachment. In addition, a multiinstitutional study in which various treatment modalities for positional plagiocephaly are compared is being charted.

**Conclusions**

Although preliminary, our objective nonradiographic measurement of cranial symmetry appears to be capable of grading the severity of positional plagiocephaly. This methodology may potentially be used as an unbiased means of comparing different treatment modalities in longitudinal studies in a multiinstitutional trial.

**References**

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