Quantification of Plagiocephaly and Brachycephaly in Infants Using a Digital Photographic Technique

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Objectives: **The aims of the study were: (1) to develop a technique to quantify plagiocephaly that is safe, accurate, objective, easy to use, well tolerated, and inexpensive; and (2) to compare this method with tracings from a flexicurve ruler.**

Design: **A case-control study of 31 case infants recruited from outpatient plagiocephaly clinics and 29 control infants recruited from other pediatric outpatient clinics.**

Participants: **Infants in the study had been diagnosed with nonsynostotic plagiocephaly or brachycephaly and were between 2 and 12 months old.**

Interventions: **Infants' head shapes were measured using (a) digital photographs of a head circumference band and (b) a flexicurve ruler. Flexicurve tracings were scanned, and both the digital photos and the scanned flexicurve tracings were analyzed using a custom-written computer program.**

Main Outcome Measures: **The oblique cranial length ratio was used to quantify cranial asymmetry, and the cephalic index was used to quantify the degree of brachycephaly.**

Results: **The infants tolerated the photo technique better than the flexicurve. Also, mothers preferred the photo technique. There was less within-subject variance for the photos than for the flexicurve measurements. The results suggested that an oblique cranial length ratio of ≥ 106% can define plagiocephaly and that a cephalic index of ≥ 93% can define brachycephaly.**

Conclusions: **The photographic technique was better accepted and more repeatable than the flexicurve measuring system. We propose that "normal" head shape is indicated in infants with both an oblique cranial length ratio of less than 106% and a cephalic index of less than 93%.**

KEY WORDS: *brachycephaly, cephalometry, plagiocephaly*

Along with an increase in referrals to clinics of infants with nonsynostotic plagiocephaly (NSP) and brachycephaly, there is an escalating interest in the measurement of head shape to determine degree of deformity. Several methods have been employed to quantify the severity of misshapen infant heads, but there is no gold standard. The technique needs to be safe, accurate, objective, easy to use in the field, and tolerated well by infants and by their parents. In order to establish the prevalence of NSP, there must be a measurement cutoff point for the purpose of NSP diagnosis.

Plagiocephaly comes from the Greek, meaning oblique; therefore, strictly speaking, a nonsynostotic brachycephalic head shape with minimal oblique skewness is not plagiocephalic. However, in our experience, this variation of flat head concerns parents as much as the skewed head shape, and we have decided to include these cases in this study.

Many different methods for quantifying craniofacial asymmetry have been reported in the literature, including visual assessment (Hunt and Puczynski, 1996; Rekate, 1998; Carson et al., 2000), articulated rulers (Watson, 1971), tape measure (Rogers, 1984), calipers (Moss, 1997; Littlefield et al., 1998; Kelly et al., 1999a; Mulliken et al., 1999), computed tomography (Dias et al., 1996; Glat et al., 1996; O'Broin et al., 1999), flexible strips (Chang et al., 2001; Loveday and de Chalain, 2001), three-dimensional (3-D) photogrammetry (Littlefield et al., 2004), and photographs (Clarren, 1981; Donegan et al., 1996). The main difficulty with many of these methods is that each time the measurement is made, there is a subjective decision as to the originating point of the measurements. There

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are other limitations. Safety is a concern when calipers are used with fussing or wriggling infants. In the case of computed tomography, one must consider anesthesia, radiation dosage, and expense. Flexible strips are less invasive than other techniques, but require firm pressure to fit the strip to the head shape. Thermoplastic strips require time for the strip to set to shape. Photographs have proven unreliable previously, due to parallax error and to hair that masks the shape of the head (Clarren, 1981; O'Broin et al., 1999); 3-D laser scanning and photogrammetry techniques are promising, but they are expensive and less portable than other methods.

Regardless of the cephalometric method used, measures of head shape need to be quantified, either manually or by computer. Historically, assessment of the severity of NSP has been based on parental scales (Pollack et al., 1997; O'Broin et al., 1999; Vles et al., 2000), visual assessment ratings (Konishi et al., 1986; Cheng and Au, 1994; Pople et al., 1996; Carson et al., 2000; Ellenbogen et al., 2000; Chang et al., 2001), actual millimeters of difference between two cross-diagonal measurements (Moss, 1997), angles between the midline and the shortest and longest cross-diagonal lengths (Clarren, 1981; Abbott et al., 1998; David and Menard, 2000), and indices based on ratios of transcranial lengths (Chang et al., 2001; Loveday and de Chalain, 2001).

It appears that there has been no consistent technique for assessing the degree of head asymmetry in plagiocephalic infants or for defining what might be within the range of normal. This study employed a digital photographic method in which custom software takes measurements from digital photos of infant heads. The photographic technique was compared with head-ring tracings made with a flexible strip, which is the method currently used in clinical practice in New Zealand.

Methods

Thirty-one case patients and 29 control subjects between the ages of 2 and 12 months were recruited for the study. The recruitment period ran between January and April 2001. The case infants, who included both new and follow-up patients diagnosed with NSP, were recruited from plagiocephaly clinics at the Middlemore Craniofacial Clinic, Auckland, New Zealand. Control infants were recruited from other pediatric medical outpatient clinics at Starship Children's Hospital, Auckland, New Zealand. Parents were given pamphlets and a verbal explanation of the study. Interviews were conducted in the infant's home after the mother signed a consent form. The first author and one other trained assistant conducted the interviews. The Auckland Ethics Committee approved the study.

Each infant's head was photographed wearing a head circumference band and was measured with a flexible strip or *flexicurve.* The infants were randomly assigned to have either the photo or the flexicurve measure first. Sets of three photos and three flexicurve measurements were made for each infant. The infant's reactions during each procedure were noted by the researcher and graded as very happy, fairly happy, neutral, fairly unhappy, or very unhappy. After the procedures, the parent was asked to say which method she preferred. Age and ethnicity were also recorded.

Photographic Method

In very young infants, the child was photographed lying in the mother's arms or over the mother's shoulder, with the top of the head free. Those infants who could sit supported or alone were seated on the mother's knee or on the floor, and were given a toy to distract them while they were prepared for photography (Fig. 1).

A small yellow cape was placed over the infant's shoulders in order to limit the possibility that the analysis software would confuse surrounding colors with the headband colors. A close-fitting stocking cap (a piece of nylon stocking with a knot tied in one end) was then placed on the infant's head to flatten the hair and to provide a hygienic base on which the head circumference band and the yellow ID sticker could be placed. The headband consisted of a soft, stretchy blue ring made of a 7-mm–wide strip of covered neoprene that is positioned around the head circumference (i.e., above the eyebrows at the front and extending around the maximal occipital protuberance at the back). Sliding red and green markers, for nose and ears, respectively, were attached to the band. The nose and ear markers were adjusted to indicate (1) the center of the nose and (2) the upper anterior-most point of the attachment of the pinna. The ear markers, viewed from above the head, appeared semicircular, whereas the nose marker appeared as a red rectangle, centered at the nose and approximately tangent to the head outline. The length of the red bar was 50 mm, and was used to determine the scale of the digital photographs of the head. Three sizes of headbands were used to accommodate different head circumferences.

A Sony DSC-S50 digital camera (2.1 megapixels; Sony Corp., Tokyo, Japan) with a pivoting LCD screen was used to take digital photographs of the head circumference ring from approximately 800 mm above the vertex of the head until three acceptable photos were obtained. Those photos that showed significant tilt or any head or neck outside of the band (with the exception of protruding ears) were excluded from analysis (see Fig. 1G). All the retained photos clearly defined the head shape in that plane, with the ear and nose markers clearly visible. The images were cropped to contain the headband and markers. Occasionally, it was necessary to perform minor editing of the images in order to delete competing primary colors in the background; this was carried out using image editing software (PhotoImpact, version 4.2; Ulead, Torrance, CA).

A computer program, HeadsUp™, was written to analyze the photographs. Using the reference measure and the primary colors of the band and markers, it calculates a number of physical aspects including cephalic index, head circumference, distance of each ear from the center of the nose, maximum and minimum transcranial (oblique) lengths, and oblique cranial length ratio. It does this by drawing a line between the ear markers, and the center of the line effectively becomes the "center" of the head. From this point, a line is drawn to the

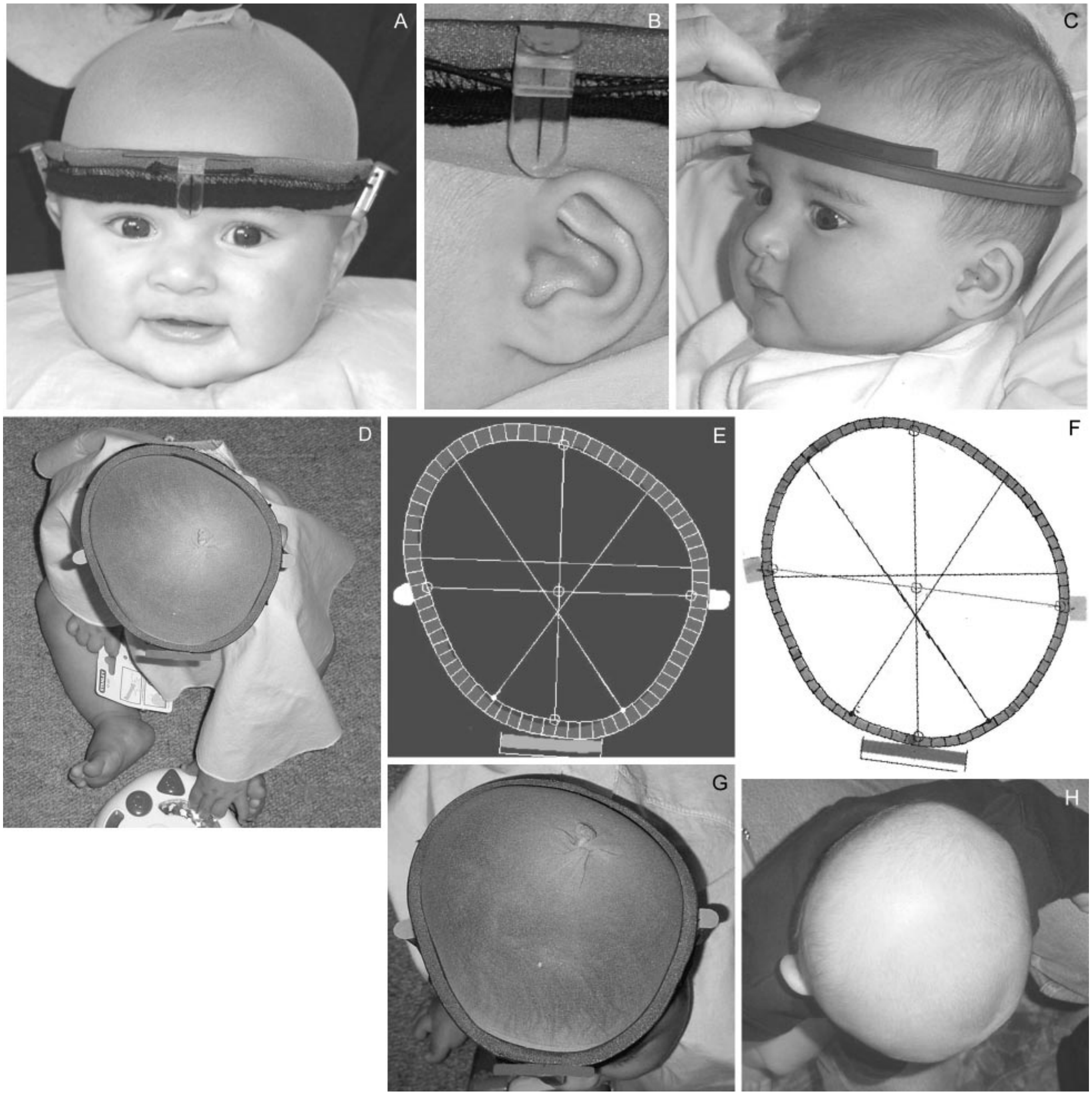

FIGURE 1 Examples of HeadsUp™ photographs and processing. A: The HeadsUp™ band in place. B: Close-up of ear marker. C: Applying the flexicurve ruler. D: Infant with severe left occipital plagiocephaly, showing band placement and photographic posture. E: HeadsUp™-processed view of photo in D, showing head length, head breadth, ear positions, and oblique cranial lengths. F: HeadsUp™-processed view of flexicurve tracing of child in D. G: Same child as in D. This photo was discarded, because significant head tilt was demonstrated by the face being visible outside the band. H: Child with occipital plagiocephaly, without band, showing difficulty of defining head tilt and ear and nose positions (forehead is at lower right).

center of the nose marker, and this point then becomes 0° on the circumference of the head. Measurements are made at 1° intervals around the head from the center. If the band is partially obscured (e.g., by slight tilt or by parietal eminences), HeadsUp™ can extrapolate the band shape over short distances.

It has been shown (Lo et al., 1996) that in NSP there is minimal deviation of the midline of the cranial base, and therefore, the line between 0° and 180° was assumed to be the midline and head length. HeadsUp™ calculates the widest head breadth taken at right angles to the midline and can thus calculate the cephalic index (breadth/length × 100).

HeadsUp™ also calculates pseudo- or derived frontozygomatic (FZ) points on the head circumference, combining published data of head circumference versus age and outer canthal distance versus age (Hall et al., 1989) to graph the outer canthal distance versus head circumference. The separation of FZ points was defined to be the outer canthal distance plus 5%. It should be noted that the frontozygomaticus is below the level of the eyebrows (Kolar and Salter, 1997). Because the

TABLE 1 Study Population Characteristics

Variable	Case (n = 31) n (%)	Controls (n = 29) n (%)	χ^2 (p Value)
Gender			3.26 (.07)
Male	23 (74.2)	15 (51.7)	
Female	8 (25.8)	14 (48.3)	
Ethnicity			5.88 (.05)
New Zealand/European	21 (67.7)	16 (55.2)	
Maori/Pacific	4 (12.9)	11 (37.9)	
Other	6 (19.4)	2 (6.9)	

TABLE 2 Paired *t* Tests of Standard Deviations of Sets of Photo and Flexicurve Measurements

Variable	Photos SD	Flexi-curves SD	t Value	p Value
Head circumference	0.55	0.45	1.30	.20
Cephalic index	1.02	1.75	−4.31	<.0001
OCLR*	0.88	1.82	−4.79	<.0001
L ear angle	0.97	3.89	−7.27	<.0001
R ear angle	0.96	3.83	−7.08	<.0001
Head area	3.66	2.99	1.30	.20

* OCLR = oblique cranial length ratio; L = left; R = right.

HeadsUp™ band lies just above the eyebrows, the derived FZ point lies on the band above this landmark.

The main measure of asymmetry from one side of the head to the other is the oblique cranial length, measured from the derived FZ point on the right forehead to a point 40° to the left of the posterior midline, and vice versa. The oblique cranial length ratio (OCLR) is therefore the ratio of the longer oblique length, or cross-diagonal length, to the shorter oblique length, expressed as a percentage. A result of 100% would indicate perfect symmetry, whereas a result of, say, 115% would indicate a highly asymmetric head shape. We chose 40° to either side of midline as a consistently likely point at which occipital flattening would be evident in most cases of NSP.

Although HeadsUp™ calculates several measurements, the measures used for this study were head circumference, cephalic index, OCLR, the difference between the two transcranial diameters, the angle of the ears from midline, and total head area bounded by the blue band. All results were from HeadsUp™, version 1.09.

Flexicurve Method

A fine-gauge flexicurve ruler was no longer commercially available at the time of the study, and those of standard size were found to be too hard and too heavy, especially for very young infants. A substitute was made from 32-grade solder wire inserted into silicone tubing, which then was sealed at each end (Fig. 1C). The flexicurve was placed around the head circumference in the same position as the photo bands, and then pressed to conform to the shape of the head. While the flexicurve was still in position, the nose and ear positions were marked; then the flexicurve was removed and carefully laid on a piece of paper. The inside shape was traced on to the paper, the nose and ear positions being marked. Three tracings were made for each infant, with the infant identification written in black inside each tracing. Ear and nose markings were removed between measurements.

A blue calligraphy pen, 5 mm wide, was then used to trace around the outside of each head-shape tracing. Red and green cardboard markers identical to those used on the bands were attached to the marked ear and nose positions, and the page was then scanned into the computer. The images were then analyzed using HeadsUp™ in the same way as the headband photos.

Statistical analysis was carried out using SAS (Release 8.0, SAS Institute Inc., Cary, NC). *T* tests were performed on the mean measurements from the two methods. Variability of photo and flexicurve measurements was established by calculating the standard deviations (SD) of each set of photo and flexicurve measurements for each baby, and then performing paired *t* tests on the SDs.

Results

There was no significant difference between the mean ages of the cases and controls; the mean age of the cases was 28.8 (SD = 11.7) weeks and of the controls, 26.9 (SD = 13.0) weeks. Table 1 shows the sex and ethnicity of the infants. More males than females were in the case group, although this difference was of borderline significance ($p = .07$). The ethnic proportions between the two groups differed significantly ($p = .05$), with more Maori and Pacific Island children in the control group and more ''other'' ethnicities in the case group.

Overall, 65% of mothers preferred the photographic method, 15% preferred the flexicurve method, and 20% expressed no preference ($p < .0001$). There was no difference between cases and controls in the mother's preference for a particular method. Similarly, there was no difference between cases and controls in the infants' reactions to the methods. Overall, 8.3% of the babies were categorized as fairly or very unhappy during the photo method, compared with 36.2% categorized as fairly or very unhappy during the flexicurve method ($p < .0001$).

The mean time to set up and to perform the three measurements was approximately 4 minutes for each method. However, the flexicurve measurements required additional time for outlining the tracings, adding markers, and scanning pages in preparation for computer analysis.

Paired *t* tests on the standard deviations of the photo and flexicurve sets for each infant showed that for both cases and controls, there was less variation in the photo measurements than in the flexicurve measurements for cephalic index, OCLR, and right and left ear angles ($p < .0001$). No significant differences were seen for head circumference or for total area (Table 2).

Using the photo data only (Table 3), the mean cephalic index and OCLR were significantly different between cases and controls ($p < .0001$), as was expected. There was a wide range for both variables, but more particularly with the case infants.

TABLE 3 Photo Data Only: Measurements of Case Infants versus Control Infants

Variable	*Cases (n = 31)* Mean (SD)	Minimum	Maximum	*Controls (n = 28)* Mean (SD)	Minimum	Maximum	*t Value (p Value)*
Head circumference (cm)	42.67 (1.91)	38.03	45.55	41.82 (2.67)	37.37	46.67	1.42 (.16)
Cephalic index	92.18 (6.74)	77.23	103.60	85.03 (5.27)	76.90	95.20	4.50 (<.0001)
OCLR (%)*	107.81 (4.50)	100.70	116.55	102.77 (2.22)	100.10	108.00	5.54 (<.0001)
Transcranial difference (mm)	10.09 (5.49)	1.00	21.5	3.55 (2.83)	0.00	10.00	5.83 (<.0001)
L ear angle (°)	93.77 (6.58)	81.67	109.00	91.11 (4.78)	78.67	97.67	1.76 (.08)
R ear angle (°)	86.22 (6.54)	71.00	98.00	88.89 (4.78)	82.00	101.33	−1.78 (.08)
Head area (cm^2)	143.43 (12.68)	113.27	164.40	137.20 (17.69)	108.40	168.53	1.57 (.12)

* OCLR = oblique cranial length ratio; L = left; R = right.

In both cases and controls, the left ear angle was greater than 90° from the nose position. The angle was greater for the case infants, indicating that overall, their right ears were more anteriorly placed than their left ears. This was marginally significant ($p = .08$). There was no difference detected between cases and controls for either head circumference or total head area. When cephalic index and OCLR were plotted against each other, the controls were clustered mostly in the area below a cephalic index of 93% and an OCLR of 106%, with some overlap between cases and controls (Figure 2).

To assess interrater reliability, both the researcher and the assistant used the two methods to measure six babies. The means for each operator and subject were put into a generalized linear model; no significant difference was found between the two operators for cephalic index or OCLR for either photo or flexicurve measurements.

Discussion

Differing approaches to the problem of how to measure infant head shape are documented in the literature. Some (Hunt and Puczynski, 1996; Rekate, 1998; Carson et al., 2000) regard visual assessment as the best diagnostic test. This is obviously an essential clinical tool; however, it does not quantify the deformity or allow for objective assessment of improvement at follow-up. Sliding and spreading calipers used for the measurement of infant heads have been widely reported in the literature (Ripley et al., 1994; Moss, 1997; Pomatto et al., 1997; Littlefield et al., 1998; Kelly et al., 1999b; Mulliken et al., 1999). They require significant experience to reduce interobserver error (Rekate, 1998) and may involve subjective decisions about caliper placement. The points at which transcranial asymmetry is measured are usually defined as the mid-

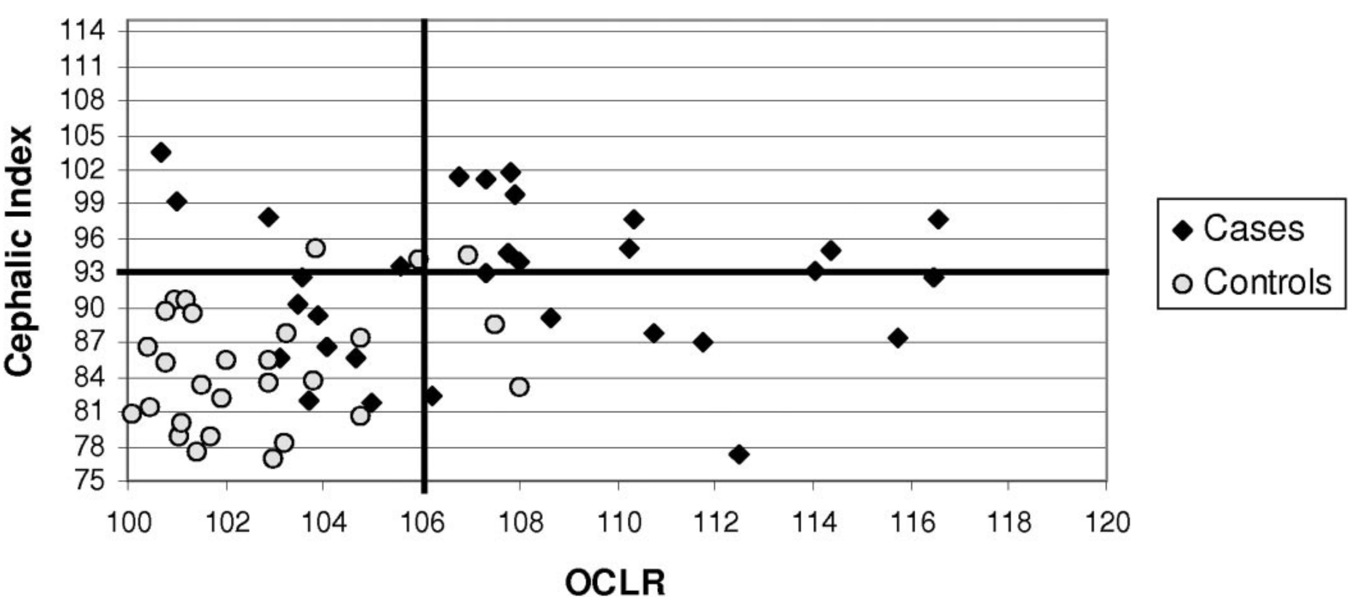

FIGURE 2 Determination of cutoff points for cephalic index and oblique cranial length ratio (OCLR). "Normal" head shapes are in the lower left quadrant; brachycephaly is in the upper left quadrant; plagiocephaly is in the lower right quadrant; and both brachycephaly and plagiocephaly are in the upper right quadrant.

point of the flattened area on the short axis and as the point of maximal convexity on the long axis (Mulliken et al., 1999). In the plagiocephaly literature, it is rare to find discussion of safety and compliance issues relating to caliper measurement, particularly when used with squirming or fussy infants. Kolar regards children between 6 months and 2 to 3 years as ''difficult, if not impossible'' to measure with calipers when awake (Kolar and Salter, 1997). Inaccurate location of landmarks due to displacement of soft tissue during infant caliper measurements may also be a problem (St John, 2002).

Several techniques for measuring asymmetry using 3-D computed tomographic scans have been described (Glicksohn et al., 1993; Genitori et al., 1994; Dias et al., 1996; Glat et al., 1996; Lo et al., 1996; O'Broin et al., 1999). Although computed tomographic scans are useful, the radiation dose and anesthetic needed mean that the method is used only with the most severely disfigured infants (Genitori et al., 1994; O'Broin et al., 1999). Striped patterns of projected light have been deemed ''unhelpful'' in assessing NSP, due to hair that masks the landmarks and features (O'Broin et al., 1999). Flexible strips or flexicurve rulers have been used to record the head shape (Robson, 1968; Baum and Searls, 1971; Rutter et al., 1993; Chang et al., 2001; Loveday and de Chalain, 2001). Either a tracing is made around the inner surface or the strip is scanned, producing a head-shape image. Manual or computer measurements then can be made from the image. Compliance issues for this technique have not been described previously. Frontal, lateral, and vertex photographs of plagiocephaly cases have been used (Rutter et al., 1993; Littlefield et al., 1998; O'Broin et al., 1999; Panchal et al., 1999); however, they are difficult to standardize (O'Broin et al., 1999), the hair obscures the outline, and measurements may be prone to error (Clarren, 1981; Jeffries et al., 1995; Donegan et al., 1996; Panchal et al., 1999).

There have been few studies using photography combined with computer calculations to record and quantify head shape. Becker (1998) photographed facial deformities with a digital camera, and then used a specially written software program to analyze distance, angle, and area; Donegan et al. (1996), with a computer to process a photographic image, used a calculated centroid to produce a graph that showed asymmetry. Neither of these authors addressed the problem of hair obscuring the head-shape outline. A more recent Taiwanese study (Chang et al., 2001) used a strip of splint material to form a head-shape ring, which was then scanned and analyzed using a computer program to output an asymmetry index. Promising advances in 3-D laser and photogrammetric systems have recently allowed for comprehensive 3-D digitization of head shape, albeit very expensively (Littlefield et al., 2004).

Using a new photographic measuring method in combination with the HeadsUp™ software, we have shown that for measures of particular relevance to plagiocephaly (i.e., cephalic index, OCLR, and ear angles), the photographic technique was much less variable than the flexicurve method. Both methods measured head circumference and area similarly, but the ear angle marking was particularly unreliable with the flexicurve.

HeadsUp™ uses a novel method to extract head contour from digital photographs. First, by using a headband of known thickness, HeadsUp™ is able to infer the inner contour of the band by interpolation, even if the inner contour is not visible due to parietal occlusion. Therefore, automatic subtraction of the band thickness from the outer profile of the headband to infer the actual head contour provides more accurate measurement than previous photographic techniques do, because the HeadsUp™ process eliminates the effect of head-shape error that can be introduced by parietal protuberance. This contrasts with other photographic techniques, in which slight changes to the infant's head position can change the head profile dramatically. Second, the band is complete with integrated markers for the nose and ear positions, which means that every photo taken may be oriented correctly relative to other photos of the same head, further decreasing variability and error, and allowing for quantification of deformation relative to the ears. Third, by using primary colors for the markers, and by masking spurious background colors with the yellow cape, the detection of head contour becomes a trivial computing problem—our experience indicates that it is very rare that the algorithms involved do not reliably pick up the correct shape of the headband. Fourth, the fact that measurements can be taken without moving the band from the head (as is needed with flexible strips) is also important, because it eliminates one potentially nontrivial source of error. These factors, combined with instantaneous image processing (rather than having to trace the shape of the baby's head by eye), make the HeadsUp™ technique far more reliable and efficient than previous techniques that relied on photography.

One benefit of digital photography is that one can immediately check photographs to ensure that the orientation and lighting are correct. The advantage of the blue headband is that it allows one to verify instantly whether orientation is correct, and whether any objects interfere with the image. Photography can continue until three photos that comply with the requirements are obtained, with unsuitable images being deleted. The common anthropometric practice of using the mean of three measurements was used, because the perfect image might not have been taken every time.

We have shown that the head shapes of the plagiocephalic cases varied significantly from the controls, from extremely skewed parallelogram profiles to symmetrically shaped heads with central (brachycephalic) flattening. Some infants had both problems. Both cephalic index and OCLR are therefore necessary in order to quantify flattening. Cephalic index is a simple and useful measure of how dolichocephalic or brachycephalic the head shape is: a value below 70% indicates an extremely narrow head and a score of 100% signifies a head that is as wide as it is long. There is no consistent cutoff point in the literature defining brachycephaly. It has been defined as a cephalic index of ≥80% (Bass, 1987; Hall et al., 1989), ≥82% (Dekaban, 1977), and ≥85% (Loveday and de Chalain, 2001). Some clinics use 2 SDs above published means to define brachycephaly, which leads to approximately 88% as the cutoff for infants 6 to 12 months old (Kolar, 2004). However, these means were based on normative data collected before supine sleeping recommendations were issued for the prevention of Sudden Infant Death Syndrome. In this study, the controls had a mean cephalic index of 85.0 (SD = 5.3). In a subsequent cohort of 200 normal New Zealand infants followed through to 2 years, the mean cephalic index at 4 months was 84.9 (SD = 6.2) and at 8 months was 83.8 (SD = 5.7; Hutchison et al., 2004). 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), so perception of what is a normal cephalic index is likely to change as supine sleeping becomes more prevalent. It may be necessary to redefine normal cephalic indices for children in countries where the supine sleep position has been adopted.

For plagiocephalic head shapes, the OCLR measurement allows for an objective measurement of asymmetry. The derived FZ point, by being tied to head circumference, allows for increases in the infant's frontal size, whereas the 40° point to either side of the posterior midline is a compromise in terms of a consistent point at which oblique posterior flattening is likely to occur. OCLR, being a ratio, allows a more consistent approach to asymmetry in differently sized children than the actual difference, which takes no account of head size. In addition, the measurement of ear position allows for documentation of forward ear migration ipsilateral to posterior flattening, a feature often seen in NSP (Huang et al., 1996).

The distribution of cephalic index and OCLR in Figure 2 shows the overlap between cases and controls in our sample, reflecting the fact there were some mild or resolving cases in the case group, and there were some infants in the control group who either were untreated or had parents who were unconcerned with the condition. The five controls outside the cutoff lines suggested in Figure 2 had been noted at interview as having an obvious head-shape deformity. However, the study protocol was to randomly select patients from clinics without defining the presence of plagiocephaly, and in any random sample of the population, one would expect the possibility of the condition's occurrence. We suggest cutoff points of 93% for cephalic index and 106% for OCLR. Choosing higher levels would lead to fewer cases being identified; conversely, lower levels would include infants who would otherwise be considered within normal limits. The true definition of a "normal" head shape would require a large study using different ethnic groups and recording the predominant sleeping positions used. In particular, there is a need for further work to establish age-specific norms for cephalic index.

It is recognized that there are several limitations to this study. The cases consisted of both brachycephalic and skewed head shapes (i.e., some had one, some had the other, and some had both configurations). This, in combination with the fact that there was overlap between some obvious cases among the control group, and some resolving cases in the case group, meant that it was not viable to use a receiver operated characteristic (ROC) analysis to determine cutoff points for cephalic index and OCLR. However, after plotting cephalic index against OCLR, we have proposed the above cutoffs. A ROC analysis of cases and controls in a much larger study might better resolve the issue of where to draw the line between normal and abnormal.

The head circumference band only defines head shape in two dimensions. However, plagiocephaly is a 3-D problem, and thus, displacement of head volume into the parietal or lower occipital areas cannot be assessed with our technique. Therefore, the true nature and severity of the deformity may not always be obvious in the vertex view. In practice, however, most NSP deformations are well represented in the circumferential plane, which is one reason for the use in New Zealand of the flexicurve measuring system. Although 3-D laser and photogrammetric systems are now available, at present they are expensive, not readily available, and not as portable as the HeadsUp™ system.

Another potential limitation is the 40° posterior point of the OCLR lines. It was chosen to suit most head deformities and it seems to work well for simplicity and consistency. HeadsUp™ also can choose the posterior OCLR points heuristically, in a well-defined way that approximates a human's choice of points to place calipers when taking diagonal measurements, but for this study it was decided to use the simpler and more explicable 40° point. Finally, training and experience in the technique are essential in order to minimize parallax error due to movement or tilt of the head during photographing.

The HeadsUp™ photo technique for quantifying head shape has proved to be simple, quick, and acceptable to parents and children. The method provides a good overall measure of head shape in the head circumference plane. The portable, low-cost nature of the system, in conjunction with the immediate digitization of measurements, points to its potential as a research tool in experienced hands. It enables the cost-effective acquisition of head-shape data on a large scale, with low error rates and good interrater reliability. The method has subsequently been used approximately 1000 times in a prospective cohort study of 200 infants followed to 2 years, and there was only one occasion in which an infant refused to cooperate and photographs could not be obtained.

Conclusions

We have endeavored in this study to overcome some of the difficulties associated with both measuring infant head shape and calculating asymmetry. The photographic technique has proved to be inexpensive, simple, portable, and very well tolerated by both babies and mothers, and has been shown to be less variable on measures relevant to plagiocephaly than the flexicurve measurement system that is in use in New Zealand clinical practice. By using a stocking cap, the problem of hair masking the true head shape is overcome. The photographs can be taken at home with the infant sitting comfortably in the mother's arms or playing on the floor. The headband allows for true measurement in the head circumference plane. A custom analysis software tool, HeadsUp™, has been developed which allows for a comprehensive set of measurements to be quickly produced, so that repeated measurements over time can be stored in the infant's file to assess the ongoing development or resolution of the plagiocephalic condition.

Simple criteria have been proposed for the clinical diagnosis of nonsynostotic plagiocephaly, namely a cephalic index of 93% or greater, or an oblique cranial length ratio of 106% or greater. These thresholds are conservative, but we believe they can be qualitatively supported on the basis of clinical experience.

The most important contributions of this study are (1) the development of a software tool and associated methodology for quickly and accurately taking infant head measurements, and (2) the development of diagnostic criteria based on analysis of our data. Together, these have opened the way for a longitudinal study to follow the natural history and prevalence of NSP (Hutchison et al., 2004).

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HeadsUp™ Software

A full description of the methodology and HeadsUp™ program, including source code in Java, is available at the following address, and is free for noncommercial use: http://www.health.auckland.ac.nz/paediatrics/staff/lynne_hutchison.html.

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