Eur J Pediatr (2006) 165: 149–157
DOI 10.1007/s00431-005-0011-1

ORIGINAL PAPER

**Leo A. van Vlimmeren · Tim Takken · Léon N. A. van Adrichem · Yolanda van der Graaf · Paul J. M. Helders · Raoul H. H. Engelbert**

# Plagiocephalometry: a non-invasive method to quantify asymmetry of the skull; a reliability study

Received: 22 April 2005 / Revised: 16 August 2005 / Accepted: 19 August 2005 / Published online: 7 October 2005


**Abstract** Deformational plagiocephaly (DP) in newborns and very young children is a common problem in daily practice. The intrarater and interrater reliability of plagiocephalometry (PCM), a new, non-invasive, inexpensive instrument to assess and quantify the asymmetry of the skull, is evaluated at the outpatient Department of Physical Therapy of the Bernhoven Hospital at Veghel, The Netherlands. Using a thermoplastic material to mould the outline of the infant's skull, a reproduction of the skull shape is performed on paper, allowing for accurate cephalometric measurements. Fifty children (aged 0–24 months), with or without positional preference of the head, and with or without DP, were measured three times by two separate, experienced pediatric physical therapists. Intraclass correlation coefficients (ICC) regarding the measurements of the drawn lines were all above 0.92 (intrarater reliability) and 0.90 (interrater reliability). The ICCs of the plagiocephaly indicators ear deviation (ED), antero-sinistra–antero-dextra (ASAD), postero-dextra–postero-sinistra (PDPS) and oblique diameter difference (ODD) were 0.88, 0.57, 0.92 and 0.96, respectively, for the intrarater reliability and 0.90, 0.65, 0.94 and 0.96, respectively, for the interrater reliability. The ICCs of the two indices oblique diameter difference index (ODDI) and cranial proportional index (CPI) were 0.97 and 0.96, respectively, for the intrarater reliability and 0.95 and 0.92, respectively, for the interrater reliability. The limits of agreement according to Bland Altman, comprising 95% of the differences between two measurements (2 sd), were 4.3 mm (ED), 5.9 mm (ASAD), 3.0 mm (PDPS), 3.4 mm (ODD), 2.7% (ODDI) and 4.5% (CPI) for the intrarater reliability, and 3.7 mm (ED), 5.2 mm (ASAD), 2.4 mm (PDPS), 3.3 mm (ODD), 2.9% (ODDI) and 5.8% (CPI) for the interrater reliability. Conclusion: We conclude that PCM is an easy-to-apply, non-invasive and reliable measurement instrument to assess skull asymmetry with good clinical accuracy and low application costs. PCM might serve as an instrument to be used in all levels of care for children with DP, and might provide information concerning the natural course of DP, as well as the assessment of the effects of conservative treatment strategies on DP.

**Keywords** Reliability · Plagiocephaly · Torticollis · Asymmetry in infancy · Measurement

**Abbreviations** ASAD: Antero-sinistra–antero-dextra · CPI: Cranial proportional index · DP: Deformational plagiocephaly · ED: Ear deviation · ICC: Intraclass correlation coefficients · ODL: Oblique diameter left · ODR: Oblique diameter right · ODD: Oblique diameter difference · ODDI: Oblique diameter difference index · PCM: Plagiocephalometry · PDPS: Postero-dextra–postero-sinistra

L. A. van Vlimmeren
Department of Physical Therapy, Bernhoven Hospital,
Veghel, The Netherlands

T. Takken · P. J. M. Helders · R. H. H. Engelbert (✉)
Department of Pediatric Physical Therapy and Exercise Physiology, University Medical Center,
Wilhelmina Children's Hospital,
Room KB 02.056.0,
P.O. Box 85090, 3508 AB Utrecht,
The Netherlands
e-mail: R.Engelbert@umcutrecht.nl
Tel.: +31-30-2504030
Fax: +31-30-2505333

L. N. A. van Adrichem
Department of Plastic and Reconstructive Surgery,
Erasmus University Medical Center Rotterdam,
Sophia Children's Hospital,
Rotterdam, The Netherlands

Y. van der Graaf
Julius Centre for Health Sciences and Primary Care,
Clinical Epidemiology, University Medical Center,
Utrecht, The Netherlands

## Introduction

Plagiocephaly is a description of the shape of the head with flattening of one side with or without sutural synostosis [9, 17]. Deformational plagiocephaly (DP) or non-synostotic

plagiocephaly [10, 28] refers to a condition in which an infant's head becomes deformed as a result of prenatal and/or postnatal external moulding forces to the malleable and growing cranium [14, 30, 37], which often leads to an asymmetric cranium, ear misalignment and facial asymmetry [7, 30, 34]. Boere-Boonekamp et al. estimated, in 7,609 children, the prevalence of DP below the age of 6 months at 9.9% occipital and 4.7% frontal [6]. Hutchison et al. stated that the prevalence of DP increases to 19.7% at 4 months of age, but diminishes to 3.3% at 24 months of age ($n$=200) [23].

DP has been attributed to a restrictive intrauterine environment, premature birth, supine position and positional preference [1, 19, 25, 28, 30, 46]. Assisted vaginal delivery, prolonged labour, unusual birth position, multiple birth, primiparity and male gender are identified as risk factors [8, 27, 29, 30, 37]. Cranial asymmetry is associated with positional and congenital muscular torticollis [7, 49]. A causal relationship between DP and brain dysfunction, including motor development disorders, has never been established [38], whereas children with DP have an elevated risk of auditory processing disorders [3], mandibular asymmetry [44] and strabismus [10, 42]. DP is generally considered to be only of cosmetic significance, but with the potential for a negative physical and psychosocial effect [35, 42].

The degree of DP may be assessed in various ways. A pronounced plagiocephaly can easily be observed clinically, but quantification is difficult and is rarely achieved in clinical practice [4]. Radiography may define the sutural anatomy, but can not describe asymmetry of the skull [40]. Three-dimensional computed scanning is the most valid and reliable morphometry to obtain an impression of the shape of the head, but serial application of computed tomography analysis exposes infants to radiation and risks of complications from general anaesthetics [11, 31, 36]. Non-invasive alternatives are used in several studies, but without detailed information regarding reliability and validity. In many studies, various anthropometrical measurements and/or standardised photographs have been used, often in combination with the use of a sliding caliper, especially to assess the transcranial largest and smallest diameter of the neurocranium [13, 15, 23, 28, 31, 33, 34, 37, 43–45]. A clinical classification or satisfaction cosmetic outcome score to describe the severity of plagiocephaly might be helpful in a clinical setting, but subtle differences in the skull shape can not be quantified [2, 40, 48].

We have designed a new instrument to quantify asymmetry of the skull: plagiocephalometry ( PCM). With PCM, it is possible to study the natural course of asymmetries of the skull, as well as the effects of conservative treatments (physiotherapy and helmet therapy) on asymmetries of the skull. PCM is unique in assessing the shape of the skull. Besides quantification of the severity of cranial distortion in DP, it provides insight into the relations between transversal shape and the exact position of the ears and nose. It is the first clinical instrument able to provide a detailed description of reliability characteristics and with easy applicability in all kinds of research and clinical settings. Especially, the use of PCM in recording measurements over time makes it very suitable for randomised clinical trials of skull asymmetries.

The present study describes the intrarater and the interrater reliability of PCM in 50 children from 0 to 24 months of age, with or without positional preference of the head, and with or without DP. Preceding this study, we performed a feasibility study of 10 children, to examine the clinical applicability (unpublished data).

## Patients and methods

### Patients

All measurements were performed at the outpatient Department of Physical Therapy of the Bernhoven Hospital at Veghel, The Netherlands. Informed consent was obtained from all parents and the Medical Ethics Committee of our hospital approved this study. Fifty children were included

**Table 1** Clinical characteristics ($n$=50)

| | | | |
|---|---|---|---|
| Parity | First: $n$=26 | | |
| | Second: $n$=16 | | |
| | Third: $n$=5 | | |
| | Fourth: $n$=3 | | |
| Labour | Normal: $n$=36 | | |
| | Section caesarean: $n$=5 | | |
| | Vacuum extraction: $n$=6 | | |
| | Breech position: $n$=3 | | |
| Gender | Boys: $n$=34 | | |
| | Girls: $n$=16 | | |
| Sleeping position | Back: $n$=45 | | |
| | Side-lying: $n$=4 | | |
| | Prone: $n$=1 | | |
| Location of deformational plagiocephaly | No deformity: $n$=6 | | |
| | Occipital right: $n$=30 | | |
| | Occipital left: $n$=14 | | |
| | Mean | SD | Range |
| Gestational age (weeks) | 38.95 | 2.40 | 28.0–42.0 |
| Birth weight (g) | 3,253.70 | 695.54 | 765.0–4,370.0 |
| Birth height (cm) | 49.87 | 3.39 | 33.6–56.0 |
| Head circumference at birth (cm) | 34.88 | 2.37 | 23.8–38.0 |
| Head circumference at time of PCM (cm) | 42.27 | 3.12 | 36.0–52.5 |
| Age at PCM (months) | 5.54 | 4.49 | 1–24 |
| | | | 1–3 months: $n$=20 |
| | | | 4–6 months: $n$=19 |
| | | | 7–9 months: $n$=7 |
| | | | >9 months: $n$=4 |

consecutively, with or without positional preference of the head (positional or congenital muscular torticollis), and with or without DP, from December 2003 to March 2004. They were between the age of 0 and 24 months, and were included without the presence of dysmorphic features, syndromes or cerebral palsy. The clinical characteristics are presented in Table 1.

## Methods

PCM is performed with a strip of thermoplastic material (3.2-mm thick) of dimensions 18 mm×50 cm (Thermo Extra-Comfort, Non-Perfo by GeniMedical, The Netherlands), which was positioned around the infant's head at the widest transverse circumference. In less than two minutes, the ring is cured and three landmarks (both ears and nose) are marked perpendicular on the ring in a standardised manner. The ear landmark is traced off the posterior edge of the tragus, corresponding best with the meatus acousticus externus. The nose landmark is traced off the middle of the nose bridge.

In this way, it is possible to trace the position of the ears and the nose in relation to the transverse circumference and contours of the head. Afterwards, the ring is removed from the head and a fourth landmark is marked representing the middle of the posterior circumferential distance between the left and right ears, measured with a medical measuring tape. Using a standard copying machine, the upper side of the ring is copied onto paper and onto a transparent sheet. The transparent sheet is specially made for follow-up purposes

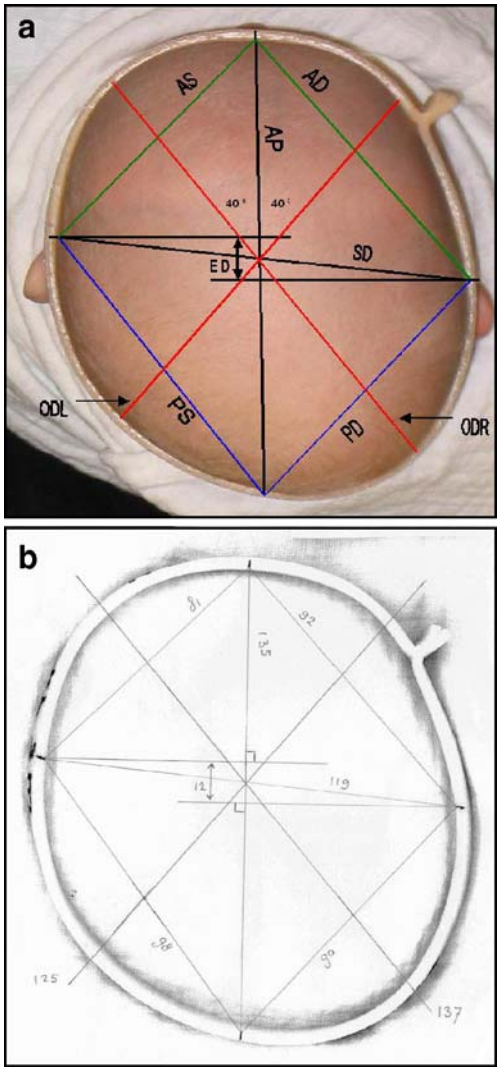


**Fig. 1a, b** Illustration plagiocephalometry: asymmetry DP left occipital of the skull (boy, aged 4 months old). **a** Photograph of child with the thermoplastic ring fitted and landmarks. The digitally drawn lines are made to illustrate the agreement with the paper copy and to explain the names of the lines. **b** Paper copy of the same ring with drawn and measured lines (in mm: ED=12; ASAD=−11; PDPS=−8; ODD=−12; ODDI=109.6%; CPI=88.1%). *AP* anterior-posterior; *SD* sinistra-dextra; AS: anterior-sinistra; *AD* anterior-dextra; *PS* posterior-sinistra; *PD* posterior-dextra; ED: ear deviation; ASAD=AS–AD; PDPS=PD–PS; *ODL* oblique diameter left; *ODR* oblique diameter right; ODD=ODL−ODR

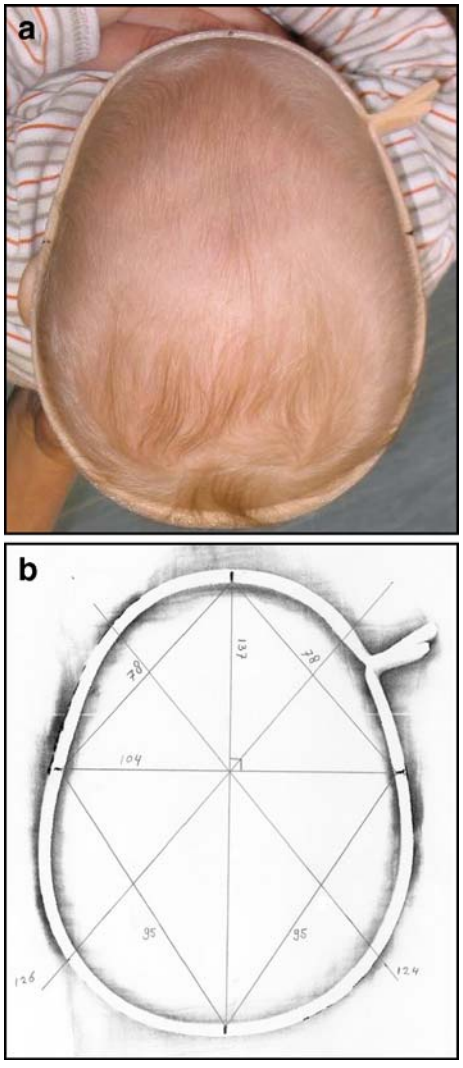


**Fig. 2a, b** Illustration plagiocephalometry: symmetric skull (boy, aged 3 months old). **a** Photograph of child with the thermoplastic ring fitted. **b** Paper copy of the same ring with drawn and measured lines (in mm: ED=0; ASAD=0; PDPS=0; ODD=2; ODDI=101.6%; CPI=75.9%)

**Table 2** Intrarater reliability PCM in millimetres, ODDI and PCI in % ($n$=50)

| PCM—intra | ICC | MD | SD | +2SD | −2SD | Range RS | 2 SD/max RS×100% |
|---|---|---|---|---|---|---|---|
| AP | 0.98 | 0.18 | 2.20 | 4.58 | −4.22 | 124–185 | 2.3% |
| SD | 0.98 | −1.06 | 2.24 | 3.43 | −5.55 | 92–148 | 3.0% |
| AS | 0.92 | −1.32 | 3.32 | 5.31 | −7.95 | 72–111 | 5.9% |
| AD | 0.93 | 0.34 | 3.27 | 6.21 | −6.89 | 79–117 | 5.5% |
| PS | 0.96 | 0.38 | 2.13 | 4.63 | −3.87 | 81–120 | 3.5% |
| PD | 0.94 | 0.10 | 2.39 | 4.89 | −4.69 | 81–117 | 4.1% |
| *ED* | *0.88* | *−0.04* | *2.14* | *4.24* | *−4.32* | *0−40* | *10.7%* |
| *ASAD* | *0.57* | *0.00* | *2.93* | *5.86* | *−5.86* | *0–30* | *19.3%* |
| *PDPS* | *0.92* | *0.10* | *1.49* | *3.08* | *−2.88* | *0–30* | *10.0%* |
| ODL | 0.99 | −0.28 | 1.41 | 2.55 | −3.11 | 107–162 | 1.7% |
| ODR | 0.99 | −0.14 | 1.47 | 2.80 | −3.08 | 111–165 | 1.8% |
| *ODD* | *0.96* | *0.02* | *1.70* | *3.41* | *−3.37* | *0–52* | *6.5%* |
| *ODDI* (%) | *0.97* | *0.06* | *1.37* | *2.81* | *−2.69* | *100.00–119.85* | *2.3%* |
| *CPI* (%) | *0.96* | *−0.82* | *2.25* | *3.68* | *−5.32* | *67.39–99.19* | *4.5%* |

*PCM* Plagiocephalometry; *ICC* Intraclass correlation coefficients; *MD* Mean difference; *SD* Standard deviation; *RS* Raw score of drawn lines and plagiocephaly indicators. DP indicators and indices in italic.

and illustrates the changes in transverse circumference. Nine lines are drawn on the paper copy and measured to the nearest millimetre, by which, the degree of asymmetry can simply be determined by calculating the differences between the lengths of the left and right lines. The clinically most important measures which present the amount of DP and proportion of the skull are arranged in three parts:

**Part 1: Position of the ears, nose and local flattening of the skull:** ear deviation (ED), anterior-sinistra−anterior-dextra (ASAD) and posterior-dextra−posterior-sinistra (PDPS).

**Part 2. Diameter difference:** oblique diameter difference (ODD). The oblique diameter left (ODL) and oblique diameter right (ODR) lines are drawn from points located 40° either side of the antero-posterior (AP) line. The ODD is calculated as: ODL−ODR. The amount 40° is chosen because this has been used by other authors formerly, probably because the differences between the diameters of the typical shape of the skull at these angles are the most outstanding. The ratio between the ODL and the ODR is calculated as the longest/shortest diameter×100%, and is called oblique diameter difference index (ODDI).

**Part 3. Transversal shape and proportion of the skull:** the ratio between the sinistra-dextra (SD) and the antero-posterior (AP) is calculated as SD/AP×100%, and is called the cranio proportional index (CPI).

By these parts, we compose four different DP indicators: ED, ASAD, PDPS and ODD. The ODDI represents the ratio of the diameter difference. To investigate the entire

**Table 3** Interrater reliability PCM in millimetres, ODDI and PCI in % ($n$=50)

| PCM—inter | ICC | MD | SD | +2SD | −2SD | Range RS | 2 SD/max RS×100% |
|---|---|---|---|---|---|---|---|
| AP | 0.98 | 0.46 | 2.27 | 4.48 | −5.40 | 122–181 | 2.5% |
| SD | 0.97 | −0.50 | 2.89 | 5.27 | −6.27 | 92–147 | 3.9% |
| AS | 0.90 | −0.90 | 3.88 | 6.86 | −8.66 | 72–113 | 6.9% |
| AD | 0.92 | −1.02 | 3.69 | 6.36 | −8.40 | 74–117 | 6.3% |
| PS | 0.93 | 0.28 | 2.93 | 6.14 | −5.58 | 81–118 | 4.9% |
| PD | 0.90 | 0.34 | 3.05 | 6.45 | −5.77 | 80–117 | 5.2% |
| *ED* | *0.90* | *0.00* | *1.86* | *3.73* | *−3.73* | *0–38* | *9.7%* |
| *ASAD* | *0.65* | *−0.26* | *2.61* | *4.96* | *−5.48* | *0–28* | *18.5%* |
| *PDPS* | *0.94* | *−0.06* | *1.22* | *2.38* | *−2.50* | *0–28* | *8.5%* |
| ODL | 0.99 | −0.26 | 1.48 | 2.70 | −3.22 | 107–162 | 1.8% |
| ODR | 0.99 | −0.34 | 1.55 | 2.76 | −3.44 | 111–165 | 1.9% |
| *ODD* | *0.96* | *0.56* | *1.67* | *3.90* | *−2.78* | *0–46* | *7.3%* |
| *ODDI* (%) | *0.95* | *0.37* | *1.47* | *3.31* | *−2.58* | *100.00–119.85* | *2.5%* |
| *CPI* (%) | *0.92* | *−0.28* | *2.91* | *5.55* | *−6.11* | *67.39–100.01* | *5.8%* |

*PCM* Plagiocephalometry; *ICC* Intraclass correlation coefficients; *MD* Mean difference; *SD* Standard deviation; *RS* Raw score of drawn lines and plagiocephaly indicators. DP indicators and indices in italic.

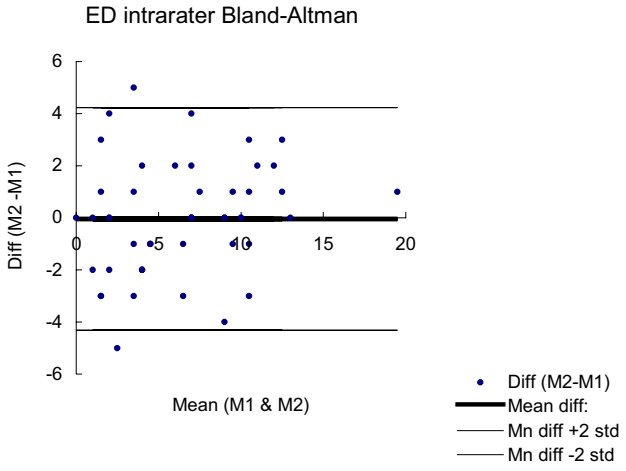


**Fig. 3** Intrarater reliability plots, Bland Altman ED

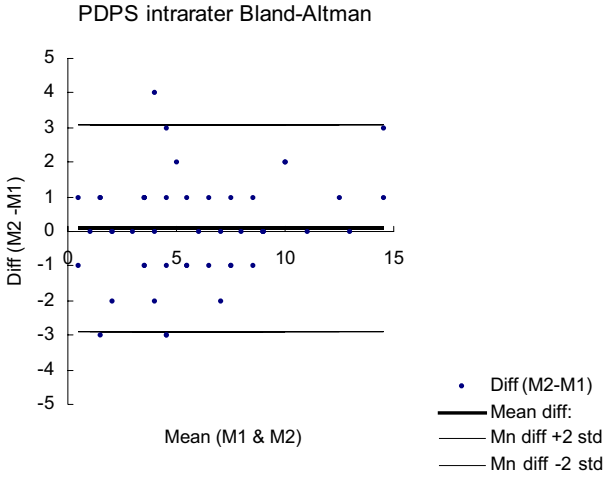


**Fig. 5** Intrarater reliability plots, Bland Altman PDPS

deformity in the transverse plane, an assessment of both asymmetry and proportional indices is required. Therefore, these measurements are necessary (Figs. 1 and 2).

Three experienced pediatric physical therapists were trained to measure PCM using a standardised protocol. Within one session of 30 min, three rings were obtained for one child. One pediatric physical therapist performed the first and the third ring tests. One of the other two pediatric physical therapists performed the second ring test. In this way, 150 rings (50 per examiner) were made for 50 children. During each session, the circumference of the head was measured. Each pediatric physical therapist copied his own ring onto paper and onto transparent sheet, and finally, drew all the lines, measured the distances in millimetres and calculated the indices.

## Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences for Windows (Version 11.0, SPSS Inc., Chicago, IL, USA) and MS Excel 98 for Windows.

Central estimators were calculated as means and standard deviations. The data regarding intrareliability and interrater reliability were analysed with intraclass correlation coefficients (ICC) with acceptable reliability criteria >0.75 [41]. The limits of agreement between the two measurements were calculated according to Bland Altman and are based on graphical techniques [5]. A plot of the difference between the measurements against their mean may be very informative and allows us to investigate any possible relationship between the measurement error and the true value.

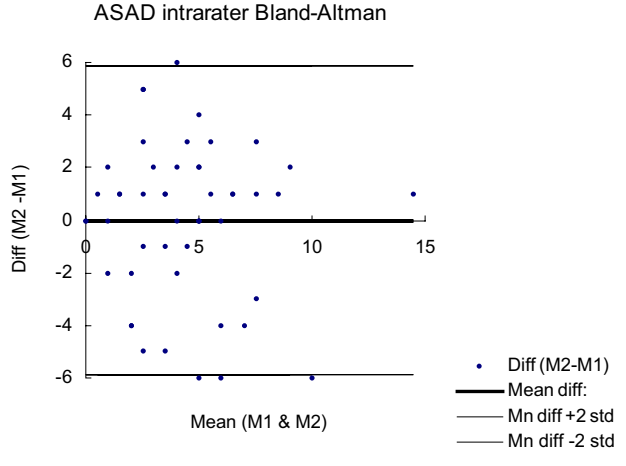


**Fig. 4** Intrarater reliability plots, Bland Altman ASAD

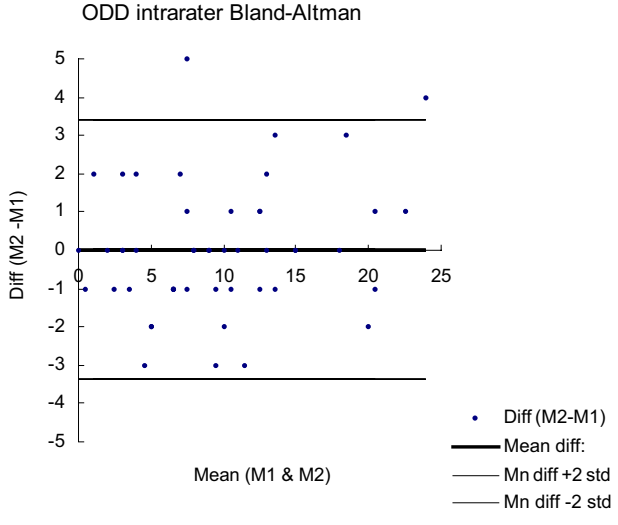


**Fig. 6** Intrarater reliability plots, Bland Altman ODD

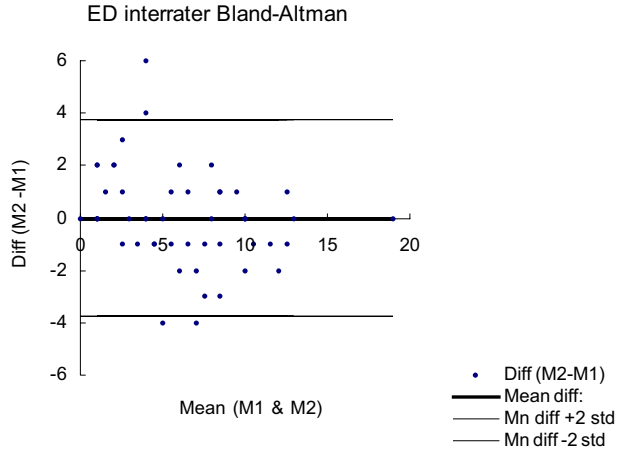


**Fig. 7** Interrater reliability plots, Bland Altman ED

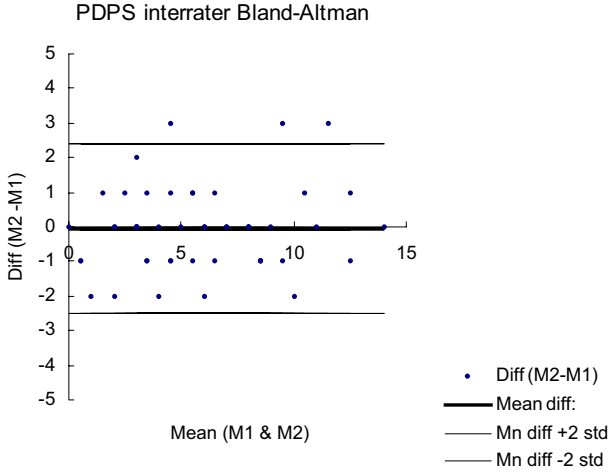


**Fig. 9** Interrater reliability plots, Bland Altman PDPS

## Results

In 50 children, 150 (50×3) thermoplastic rings were made and used for analysis. Therefore, intrarater and interrater reliability was calculated, both based on 100 measurements. We analysed all lines drawn on the paper copy, whereas the four DP indicators (ED, ASAD, PDPS, ODD) will provide detailed information concerning the asymmetry of the skull. The representation of asymmetry as a clinically significant distortion of the skull also depends on age and proportionality. Therefore, two calculated indices (ODDI and CPI) provide information about the asymmetry and proportions of the skull.

### Intrarater reliability

Intraclass correlation coefficients (ICCs) regarding the measurements of the drawn lines were all above 0.92. The ICCs of the plagiocephaly indicators ED, ASAD, PDPS and ODD were 0.88, 0.57, 0.92 and 0.96, respectively. The ICCs of the two indices ODDI and CPI were 0.97 and 0.96, respectively. The limits of agreement (Bland Altman), comprising of 95% of the differences between two measurements (2 sd), were 4.3 mm (ED), 5.9 mm (ASAD), 3.0 mm (PDPS), 3.4 mm (ODD), 2.7% (ODDI) and 4.5% (CPI), respectively (Table 2).

### Interrater reliability

Intraclass correlation coefficients (ICCs) regarding the measurements of the drawn lines were all above 0.90. The ICCs of the plagiocephaly indicators ED, ASAD, PDPS and ODD were 0.90, 0.65, 0.94 and 0.96, respectively. The ICCs of the two indices ODDI and CPI were 0.95 and 0.92, respectively. The limits of agreement (Bland Altman), comprising of 95% of the differences between two measurements (2 sd), were 3.7 mm (ED), 5.2 mm (ASAD), 2.4 mm (PDPS), 3.3 mm (ODD), 2.9% (ODDI) and 5.8% (CPI), respectively (Table 3).

The differences (2 sds) in PCM Part 1 were about 10% of the maximum lengths of the drawn lines and differences for intrarater reliability (10.7% for ED and 10.0% for PDPS), and less than 10% for interrater reliability (9.7% for ED

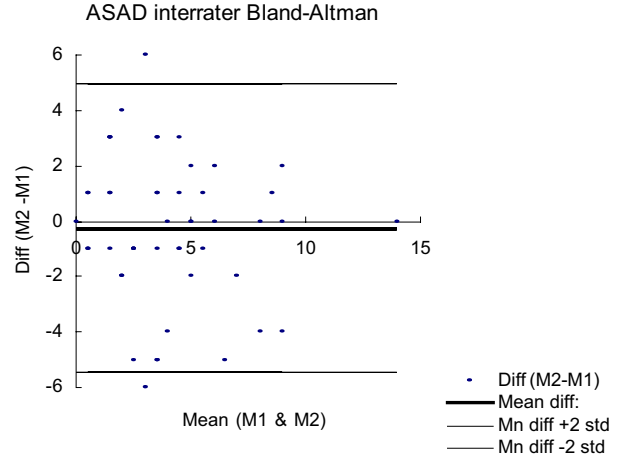


**Fig. 8** Interrater reliability plots, Bland Altman ASAD

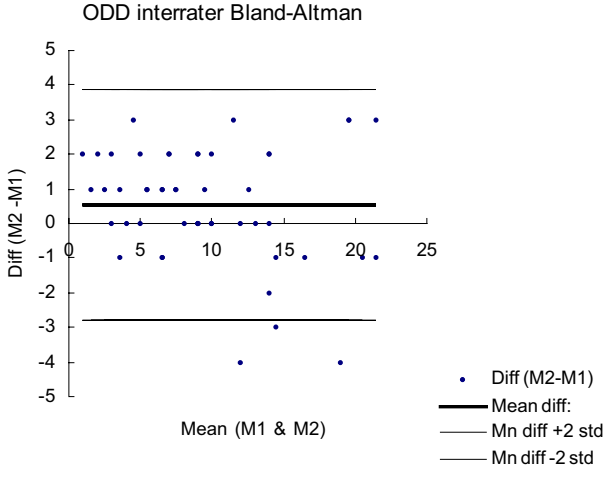


**Fig. 10** Interrater reliability plots, Bland Altman ODD

and 8.5% for PDPS). The differences between the ASAD varied to a greater extent: 19.3% for intrarater reliability and 18.5% for interrater reliability.

The differences (2sds) of the ODDs (PCM Part 2) were far less than 10% of the maximum difference scores of the oblique lengths (6.5% for the intrarater and 7.3% for the interrater reliability). The differences (2 sds) of the indices ODDI and CPI were also very small: 2.3–2.5% for the ODDI and 4.5–5.8% for the CPI, of the maximum percentage ranges. The limits of agreement are small enough to be confident that the measurements of the same child are reliable. Limits of agreement data plots (ED, ASAD, PDPS and ODD) of the intrarater and interrater reliability are visualised in Figs. 3, 4, 5, 6, 7, 8, 9 and 10. The *limits of agreement* plots visualise the distribution of the measurement data and indicate the minimal change that needs to be measured to surpass the 95% confidence interval of the measurement [5, 50]

## Discussion

Plagiocephalometry (PCM) is an easy-to-apply, non-invasive measurement instrument to assess skull asymmetry with good clinical use and low application costs. From our study, we may conclude that the intrarater and interrater reliability are statistically acceptable for the application in clinical care and research. Although several devices have been described to quantify asymmetry of the skull, most of them lack of standardised, objective and simple-to-use methods to classify cranial deformities. Reliability and validity characteristics of these instruments are scarcely reported. The amount of deformity, i.e. whether it is "mild," "moderate" or "severe," often dictates the treatment recommendations. Unfortunately, these classifications are often subjective, varying not only between specialists (craniofacial surgeons, neurosurgeons, pediatricians), but also within specialties.

Quantifying the asymmetry of the head is essential in research and clinical decision making, as well as in clinical practice. With PCM, the shape and contours of the head can be measured and recorded over time. In this way, knowledge can be gained concerning the postnatal development of cranial asymmetry and the effects of conservative treatments to influence cranial asymmetry, as well as the natural course of plagiocephaly. From clinical experience, we hypothesised that a difference of more than 5 mm in ear deviation (ED), 4 mm in postero-dextra−postero-sinistra (PDPS) and 4 mm in oblique diameter difference (ODD) illustrated obviously clinical asymmetry of the skull, and is, therefore, clinically relevant.

The indices oblique diameter difference index (ODDI) and cranial proportional index (CPI) provide additional information about the amount of asymmetry and the proportion in the growing skull. Also, from clinical experience, we hypothesised that more than 104% in ODDI illustrates obviously clinical asymmetry of the skull and is, therefore, clinically relevant and corrected for age and growth. Calculating a transcranial difference as ODDI [15, 20, 23, 31, 34, 37, 44] and a cranial index as CPI [23, 31] by using photographs or caliper measurements is not new, but these anthropometrical variables can also easily be extracted from the PCM paper copy. These aspects of PCM used in prospective studies might provide comparisons with the outcomes of other recent studies [20, 23, 37].

Conservative strategies to intervene in deformational plagiocephaly (DP) primarily consist of physical therapy and helmet treatment [15, 20, 31, 40, 48]. Preventive counselling for parents on the positioning, handling and nursing of the infant is important to minimise the risk of positional preference and to correct DP [6, 21, 22, 35, 36, 39]. Infants should be regularly positioned in a supervised prone position ("tummy time") for significantly more than 5 minutes a day [16, 21, 22, 24, 26, 39, 47]. In general, physical therapy seems to be beneficial when applied to infants of between 2 to 8 months of age [12]. DP may be treated by helmet therapy and is generally recommended between 6 and 18 months of age [32, 34].

Randomised controlled trials concerning physical therapy and helmet therapy were not found in the current literature [23, 28, 33, 45, 50]. Therefore, PCM seems to be essential in measuring the effect of conservative management of DP, as well as studying the natural course.

Our present study has some limitations. A measurement is generally considered reliable when one or more raters obtain the same outcome in a subject under the same conditions, within a time span of 24 h [18]. Although factors that could influence the outcome in our study are controlled, due to strict operationalisation, sometimes, it was difficult to completely stabilise the head of the child during three consecutive measurements.

The landmark extracted from the middle of the nose on the front of the ring is sometimes difficult to trace. To point out the middle of the nose bridge seems to require substantial experience and skills. This factor probably explains the lower correlations of the antero-sinistra−antero-dextra measurements (ASADs), referring to the asymmetries at the front of the head. Otherwise, Boere-Boonekamp et al. estimated the prevalence of DP below the age of 6 months at 9.9% occipital and 4.7% frontal, indicating that the most obvious asymmetries might be seen at the posterior side of the head and at the deviation of the ears [6]. The plagiocephaly indicators regarding these regions, ED, PDPS and ODD, have the smallest limits of agreement.

This investigation defines severity from a single vertex orientation, although, regularly, there are deformities in three dimensions. Most common and most obvious is deformity in the transverse plane; thus, for clinical purposes, PCM complies very well.

The limits of agreement plots are used to visualise the distribution of the measurement data and to indicate the minimal change that needs to be measured to surpass the 95% confidence interval of the measurement [18]. These plots of the difference between the measurements against their mean are more informative than the high correlation coefficients. They allow us to investigate any possible relationship between the measurement error and the true value [5]. In our study, the outcomes demonstrate fair reliability and show excellent possibilities for research and

clinical use. The time required to perform the analysis (obtain the thermoplastic contour, identify landmarks, trace, draw and measure lines) is about 10 minutes.

Establishing the validity of PCM is the next step in the process of further introducing PCM in clinical practice. Currently, PCM is studied in children with severe skull deformities with three-dimensional computed scanning (3D-CT), which method tests the captured head shape in cases that require 3D-CT for other medical reasons.

## Conclusion

We conclude that plagiocephalometry (PCM) is an easy-to-apply, non-invasive and reliable measurement instrument to assess skull asymmetry with good clinical use and low application costs. PCM might serve as an instrument to be used in all levels of care for children with deformational plagiocephaly (DP) and might provide information concerning the natural course of DP, as well as the assessment of the effects of conservative treatment strategies of this common problem. Although the proposal of cut-off points to differentiate between abnormal and normal is premature, in our opinion, a difference of more than 5 mm in ear deviation (ED), 4 mm in postero-dextra−postero-sinistra (PDPS), 4 mm in oblique diameter difference (ODD) and more than 104% in oblique diameter difference index (ODDI) illustrated obviously clinical asymmetry of the skull and is, therefore, clinically relevant.

**Acknowledgements** The authors thank Lonneke van Soest, PT, PCS, MA and Judith Timmers, PT, PCS, BSc of the Department of Physical Therapy, Bernhoven Hospital, Veghel, The Netherlands, for their contribution in the acquisition of the data.

## References

1. Argenta LC, Davis LR, Wilson JA, Bell WO (1996) An increase in infant cranial deformity with supine sleeping position. J Craniofac Surg 7:5–11
2. Argenta L, David L, Thompson J (2004) Clinical classification of positional plagiocephaly. J Craniofac Surg 15:368–372
3. Balan P, Kushnerenko E, Sahlin P, Huotilainen M, Näätänen R, Hukki J (2002) Auditory ERPs reveal brain dysfunction in infants with plagiocephaly. J Craniofac Surg 13:520–525
4. Besson A, Pellerin P, Doual A (2002) Study of asymmetries of the cranial vault in plagiocephaly. J Craniofac Surg 13: 664–669
5. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1:307–310
6. Boere-Boonekamp MM, van der Linden-Kuiper LT (2001) Positional preference: prevalence in infants and follow-up after two years. Pediatrics 107:339–343
7. Bredenkamp JK, Hoover LA, Berke GS, Shaw A (1990) Congenital muscular torticollis: a spectrum of disease. Arch Otolaryngol Head Neck Surg 116:212–216
8. Bridges SJ, Chambers TL, Pople IK (2002) Plagiocephaly and head binding. Arch Dis Child 86:144–145
9. Bruneteau RJ, Mulliken JB (1992) Frontal plagiocephaly: Synostotic, compensational, or deformational. Plast Reconstr Surg 89:21–33
10. Canale ST, Griffin DW, Hubbard CN (1982) Congenital muscular torticollis. A long-term follow-up. J Bone Joint Surg 64:810–816
11. Captier G, Leboucq N, Bigorre M, Canovas F, Bonnel F, Bonnafe A, Montoya P (2003) Plagiocephaly: morphometry of skull base asymmetry. Surg Radiol Anat 25:226–233
12. Carson BS, Munoz D, Gross G, VanderKolk CA, James CS, Gates J, North M, McKnight M, Guarnieri M (2000) An assistive device for the treatment of positional plagiocephaly. J Craniofac Surg 11:177–183
13. Chang PY, Chien YW, Huang FY, Chang NC, Perng DB (2001) Computer-aided measurement and grading of cranial asymmetry in children with and without torticollis. Clin Orthod Res 4:200–205
14. Clarren SK, Smith DW, Hanson JW (1979) Helmet treatment for plagiocephaly and congenital muscular torticollis. J Pediatr 94:43–46
15. Clarren SK (1981) Plagiocephaly and torticollis: etiology, natural history, and helmet treatment. J Pediatr 98:92–95
16. Davis BE, Moon RY, Sachs HC, Ottolini MC (1998) Effects of sleep position on infant motor development. Pediatrics 102: 1135–1140
17. Fenichel GM (1993) Disorders of cranial volume and shape. In: Clinical pediatric neurology, 2nd edn. Saunders, Philadelphia, Pennsylvania, pp 375–378
18. van Genderen FR, De Bie RA, Helders PJM, Van Meeteren NLU (2003) Reliability research: towards a more clinically relevant approach. Phys Ther Rev 8:169–176
19. Golden KA, Beals SP, Littlefield TR, Pomatto JK (1999) Sternocleidomastoid imbalance versus congenital muscular torticollis: their relationship to positional plagiocephaly. Cleft Palate Craniofac J 36:256–261
20. Graham JM Jr, Gomez M, Halberg A, Earl DL, Kreutzman JT, Cui J, Guo X (2005) Management of deformational plagiocephaly; repositioning versus orthotic therapy. J Pediatr 146: 258–262
21. Hunt CE, Puczynski MS (1996) Does supine sleeping cause asymmetric heads? Pediatrics 97:127–129
22. Hutchison BL, Thompson JM, Mitchell EA (2003) Determinants of nonsynostotic plagiocephaly: a case–control study. Pediatrics 112:e316
23. Hutchison BL, Hutchison LA, Thompson JM, Mitchell EA (2004) Plagiocephaly and brachycephaly in the first two years of life: a prospective cohort study. Pediatrics 114:970–980
24. Jantz JW, Blosser CD, Fruechting LA (1997) A motor milestone change noted with a change in sleep position. Arch Pediatr Adolesc Med 151:565–568
25. Kane AA, Mitchell LE, Craven KP, Marsh JL (1996) Observations on a recent increase in plagiocephaly without synostosis. Pediatrics 97:877–885
26. Kattwinkel J, Brooks J, Keenan MJ, Malloy M (1996) Positioning and sudden infant death syndrome (SIDS): update. American Academy of Pediatrics Task Force on Infant Positioning and SIDS. Pediatrics 98:1216–1218
27. Kelly KM, Littlefield TR, Pomatto JK, Manwaring KH, Beals SP (1999) Cranial growth unrestricted during treatment of deformational plagiocephaly. Pediatr Neurosurg 30:193–199
28. Littlefield TR, Beals SP, Manwaring KH, Pomatto JK, Joganic EF, Golden KA, Ripley CE (1998) Treatment of craniofacial asymmetry with dynamic orthotic cranioplasty. J Craniofac Surg 9:11–17
29. Littlefield TR, KM Kelly, JK Pomatto, Beals SP (1999) Multiple-birth infants at higher risk for development of deformational plagiocephaly. Pediatrics 103:565–569
30. Littlefield TR, Kelly KM, Pomatto JK, Beals SP (2002) Multiple-birth infants at higher risk for development of deformational plagiocephaly: II. Is one twin at greater risk? Pediatrics 109:19–25
31. Loveday BP, de Chalain TB (2001) Active counterpositioning or orthotic device to treat positional plagiocephaly? J Craniofac Surg 12:308–313

32. Miller RI, Clarren SK (2000) Long-term developmental outcomes in patients with deformational plagiocephaly. Pediatrics 105:E26
33. Moss SD (1997) Nonsurgical, nonorthotic treatment of occipital plagiocephaly: what is the natural history of the misshapen neonatal head? J Neurosurg 87:667–670
34. Mulliken JB, Vander Woude DL, Hansen M, LaBrie RA, Scott RM (1999) Analysis of posterior plagiocephaly: deformational versus synostotic. Plast Reconstr Surg 103:371–380
35. Najarian SP (1999) lnfant cranial molding deformation and sleep position: implications for primary care. J Pediatr Health Care 13:173–177
36. O'Broin ES, Allcutt D, Earley MJ (1999) Posterior plagiocephaly: proactive conservative management. Br J Plast Surg 52:18–23
37. Peitsch WK, Keefer CH, LaBrie RA, Mulliken JB (2002) Incidence of cranial asymmetry in healthy newborns. Pediatrics 10:e72
38. Persing JA (2001) Discussion: Neurodevelopment in children with single-suture craniosynostosis and plagiocephaly without synostosis. Plast Reconstr Surg 108:1499–1500
39. Persing JA, James H, Swanson J, Kattwinkel J (2003) Prevention and management of positional skull deformities in infants. American Academy of Pediatrics Committee on Practice and Ambulatory Medicine, Section on Plastic Surgery and Section on Neurological Surgery. Pediatrics 112:199–202
40. Pollack IF, Losken HW, Fasick P (1997) Diagnosis and management of posterior plagiocephaly. Pediatrics 99:180–185
41. Portney LG, Watkins MP (2000) Foundations of clinical research: applications to practice, 2nd edn. Prentice Hall, Upper Saddle River, New Jersey
42. Rekate HL (1998) Occipital plagiocephaly: a critical review of the literature. J Neurosurg 89:24–30
43. Ripley CE, Pomatto J, Beals SP, Joganic EF, Manwaring KH, Moss SD (1994) Treatment of positional plagiocephaly with dynamic orthotic cranioplasty. J Craniofac Surg 5:150–159
44. St John D, Mulliken JB, Kaban LB, Padwa BL (2002) Anthropometric analysis of mandibular asymmetry in infants with deformational posterior plagiocephaly. J Oral Maxillofac Surg 60:873–877
45. Teichgraeber JF, Ault JK, Baumgarter J, Waller A, Messersmith M, Gateno J, Bravenec B, Xia J (2002) Deformational posterior plagiocephaly: diagnosis and treatment. Cleft Palate Craniofac J 39:582–586
46. Turk AE, McCarthy JG, Thorne CH, Wisoff JH (1996) The "back to sleep campaign" and deformational plagiocephaly: Is there cause for concern? J Craniofac Surg 7:12–18
47. Visscher F, van der Graaf T, Spaans M, van Lingen RA, Fetter WP (1998) Prone position favorable for motor development of infants (in Dutch). Ned Tijdschr Geneeskd 142:2201–2205
48. Vles JS, Colla C, Weber JW, Beuls E, Wilmink J, Kingma H (2000) Helmet versus nonhelmet treatment in nonsynostotic positional posterior plagiocephaly. J Craniofac Surg 11:572–574
49. van Vlimmeren LA, Helders PJ, van Adrichem LN, Engelbert RH (2004) Diagnostic strategies for the evaluation of asymmetry in infancy–a review. Eur J Pediatr 163:185–191
50. van Vlimmeren LA, Helders PJ, van Adrichem LN, Engelbert RH (2005) Torticollis and plagiocephaly in infancy: therapeutic strategies—a review. Ped Rehab (in press)