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Association of Postnatal Anterior Facial Geometric Morphometry with Cephalopelvic Disproportion among Neonates in Jigawa State, Nigeria

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ABSTRACT

Cephalopelvic disproportion (CPD) is a major cause of obstructed labor and operative delivery worldwide, contributing to maternal and neonatal morbidity and mortality in low- and middle-income countries. Traditional antenatal prediction of CPD relies on linear fetal anthropometric measurements, which primarily reflect fetal size rather than structural configuration and have limited predictive accuracy. This study associated postnatal anterior facial geometric morphometry of neonates with CPD. A total of 160 neonates (80 CPD, 80 non-CPD) were prospectively recruited from Jahun General Hospital, Jigawa State, Nigeria. Anterior facial images were captured at a standardized distance of approximately 1 meter with subjects positioned in the Frankfurt horizontal plane, and 15 landmarks were digitized using tpsDig2 software. Generalized Procrustes analysis, principal component analysis, canonical variate analysis, and Procrustes ANOVA were performed to examine shape differences and test their significance between groups. Principal component analysis showed that the first three components accounted for 69.73% of total facial shape variation, with clear separation between groups. Canonical variate analysis revealed a Mahalanobis distance of 1.0346 and a Procrustes distance of 0.0326 between groups, both statistically significant on permutation testing (1000 rounds, $P < 0.001$). Procrustes ANOVA showed significant effects of group on centroid size ($F = 11.85$, $P = 0.0008$) and on facial shape ($F = 4.44$, $P < 0.0001$). Anterior facial shape and size differed significantly between CPD and non-CPD neonates, suggesting that anterior facial geometric morphometry was associated with CPD.

Keywords: cephalopelvic disproportion; geometric morphometrics; anteri

or facial shape; neonate; association

INTRODUCTION

Cephalopelvic disproportion (CPD) is a major obstetric condition that occurs when there is an incompatibility between the size and shape of the fetal presenting part, most commonly the head, and the maternal pelvic dimensions, thereby preventing successful vaginal delivery.[1,2] It is a leading cause of obstructed labor and operative delivery worldwide and is defined as a mismatch between the fetal head and maternal pelvis that prevents descent even after full cervical dilation. This condition remains a significant contributor to maternal and neonatal morbidity and mortality, particularly in low- and middle-income countries.[1,2,3] The burden of CPD is especially high in sub-Saharan Africa, including Nigeria, where it constitutes a major indication for cesarean section and is often associated with poor maternal and perinatal outcomes.[1]

Obstructed labor resulting from CPD may lead to severe complications such as uterine rupture, postpartum hemorrhage, fetal distress, and stillbirth.[4,5] Despite advances in obstetric care, CPD is frequently diagnosed only during labor, often after prolonged and unsuccessful attempts at vaginal delivery, highlighting the urgent need for reliable antenatal predictive methods.[2,3,6]

Traditionally, prediction of CPD relies on fetal anthropometric assessment using ultrasonography. Commonly measured parameters include biparietal diameter and head circumference; these measurements are used in assessment of fetal size and have been associated with labor outcomes, including

prolonged labor and emergency caesarean delivery.[7,8,9] However, emerging evidence suggests that these traditional anthropometric parameters have limited predictive accuracy, as they primarily reflect fetal size rather than structural configuration.[10]

These developments underscore the growing recognition that two- and three-dimensional morphology and spatial relationships, rather than simple linear dimensions, are essential in predicting delivery outcomes.[11,12,]

Most existing studies focus on linear dimensions in predicting the risk of CPD rather than shape. No study has associated postnatal geometric craniofacial morphometrics of neonates with CPD and special relationships.[13] Therefore, this study addressed this gap by associating postnatal anterior facial geometric morphometry of neonates with CPD.

MATERIALS AND METHODS

Study design and setting

The study employed a comparative, cross-sectional analytical design of anterior facial geometric morphometrics of neonates among women delivered at Jahun General Hospital, a secondary health facility in Jigawa State, Nigeria.

Participants and sample

A total of 160 neonates were prospectively recruited, comprising 80 cases (CPD) and 80 controls (non-CPD). 160 sample size were obtained using $n=(Z\alpha/2+Z\beta)^2(\sigma1+\sigma2)^2/d^2$; where $Z\alpha/2=1.96$ (95% confidence level), $Z\beta=0.84$ (80% power), $d=1.05$ (minimum detectable difference between groups),

$\sigma1$ and $\sigma2=1.5$ and 1.8 respectively (SD of CPD and those without CPD from similar studies on HC in Ekiti State, Nigeria).[1]

$n= (1.96+0.84)^2(1.5+1.8)^2 / (1.05)^2= 77.44 \approx 77.$

After dividing 77 by 2 = 38.5; therefore ≈ 39 samples is needed per group

Adjustment for Attrition (10%) $N = 39 + (0.10\times39) = 39+3.9 = 42.9 \approx 43$ per group

Therefore, a total sample of 86 was needed for the study, but to allow subgroup analyses, a total of 160 participants were recruited (80 CPD and 80 non-CPD).

Sampling technique

A consecutive sampling technique was employed. All eligible neonates who met the inclusion criteria and were delivered at Jahun General Hospital during the study period were recruited consecutively until the required sample size was achieved.

Selection criteria

Inclusion criteria: maternal informed consent; term neonates (37–42 weeks gestation); singleton births; neonates delivered vaginally (controls); neonates delivered via cesarean section for CPD (cases); and neonates with no congenital craniofacial abnormalities.

Exclusion criteria: preterm (<37 weeks) or post-term (>42 weeks) neonates; multiple pregnancies (twins, triplets); neonates with craniofacial deformities; and cesarean sections performed for reasons other than CPD.

Variables

The independent variable was anterior facial image shape, characterized through geometric morphometric landmark coordinates. Confounding variables include gestational age, maternal age and height, birth weight, parity, and birth interval.

Both the independent and confounding variables were documented within 48 hours after delivery in each participant, to avoid post-delivery changes caused by environmental, nutritional, pathological, or other factors that may affect the study variables.

Image acquisition and landmark digitization

A smartphone camera (itel A50 series, version 14.0.1, China) was used for photographic documentation of anterior craniofacial features. Open Camera software was used to disable auto mode and manually set all parameters (focal length 2.925 mm, resolution 2448 × 3264, exposure 1/50, ISO 381), allowing all images to be captured at fixed camera settings. Images were captured at a standardized distance of approximately 1 meter from the subject with the aid of a professional adjustable camera tripod stand that held the camera in a fixed position throughout the research**.** The subject was positioned in the Frankfurt horizontal plane, in which the occipital bone was placed in the plane background, allowing exploration of the anterior facial features. Adequate natural lighting was ensured, and the same smartphone and camera settings (ISO, focus, focal length, and aperture) were used throughout the study to ensure consistency. Confounding variables were documented using a questionnaire.

Data analysis

All images were converted to TPS files using tpsUtil (version 1.83, 32-bit). The TPS files were imported into tpsDig2 software (version 2.32, 64-bit), where a total of 15 landmarks (glabella, pronasale, labiale superius, labiale inferius, gnathion, exocanthion [left and right], endocanthion [left and right], alare [left and right], cheilion [left and right], and zygion [left and right]) were digitized in the same order across all images.[14] The digitized landmark data were imported into MorphoJ software (version 1.07a, 64-bit), where shape analysis was performed.[15] Generalized Procrustes analysis (GPA) was used to remove the

effects of size, position, and rotation.[16] Principal component analysis (PCA) was used to reduce the dimensionality of the craniofacial shape variables; canonical variate analysis (CVA) was used to determine shape differences between groups.[17] Procrustes ANOVA was used to statistically test the significance of shape differences between groups (CPD and non-CPD).[18] An independent-samples t-test was conducted to compare the mean differences of confounding variables between the groups

Ethical considerations

Ethical approval was obtained from the Ministry of Health, Jigawa State, Nigeria (JGHREC/2026/2589). Informed consent was obtained from all mothers, and confidentiality was maintained throughout the study.

RESULTS

Generalized Procrustes analysis

Generalized Procrustes analysis (Figure 1) was performed to remove the effects of size, position, and rotation from the landmark configurations.

Principal component analysis

Principal component analysis was performed on the Procrustes coordinates derived from anterior facial landmarks to reduce the dimensionality of the craniofacial shape variables and to identify the major patterns of variation among neonates with and without CPD (Figure 2). The first three principal components accounted for a substantial proportion of the total shape variation: PC1 explained 33.136%, PC2 explained 25.015%, and PC3 explained 11.580% of the total variation, together accounting for 69.73% of the total facial shape variation.

Canonical variate analysis

The analysis revealed clear separation between the two groups along the first canonical variate axis. The Mahalanobis distance between the CPD and non-CPD groups was 1.0346, while the Procrustes distance was 0.0326 (Table 1). Permutation testing of both distances demonstrated that the observed shape difference was statistically significant ($P < 0.001$), indicating that anterior facial shape configuration differed significantly between neonates with and without CPD.

Procrustes ANOVA

Procrustes ANOVA was performed to statistically test whether shape differences between groups were significant and to assess the effects of group membership and other sources of variation on anterior facial shape.

Centroid size analysis was performed to assess differences in overall anterior facial size between CPD and non-CPD neonates. The Procrustes ANOVA for centroid size revealed a significant effect of group on centroid size variation ($F = 11.85$, $P = 0.0008$), indicating that anterior facial size differed significantly between the CPD and non-CPD groups (Table 2). A significant individual effect was also observed ($F = 1.60$, $P = 0.0284$), suggesting significant variation in centroid size among individual specimens.

Procrustes ANOVA revealed a significant effect of group on facial shape variation ($F = 4.44$, $P < 0.0001$), indicating that the anterior facial shape configurations of CPD and non-CPD neonates differed significantly (Table 3). A significant individual effect was also observed ($F = 2.98$, $P < 0.0001$), demonstrating significant variation in shape among individual specimens. The side effect was statistically significant ($F = 28.53$, $P < 0.0001$), indicating significant differences associated with side variation. However, the individual-by-side interaction was not significant ($F = 0.51$, $P = 1.0000$), suggesting that the pattern of side variation did not differ significantly among individuals.

Multivariate analysis of variance (MANOVA) was also performed to evaluate the effects of group and individual variation on anterior facial shape (Table 4). The analysis revealed a significant effect of group on anterior facial shape variation (Pillai's trace = 0.27, $P = 0.0042$), indicating that CPD and non-CPD neonates differed significantly in their overall anterior facial shape configuration. A significant individual effect was also observed (Pillai's trace = 8.97, $P = 0.0146$), demonstrating significant variation in facial shape among individual specimens.

Independent sample t test

The results showed no statistically significant differences in parity ($p = 0.799$), gestational age ($p = 0.282$), birth interval ($p = 0.636$), maternal age ($p = 0.393$), and maternal height ($p = 0.504$) between the two groups. However, significant differences were observed in birth weight (3.02 ± 0.35 kg vs. 2.52 ± 0.46 kg; $p < 0.0001$) (Table 5).

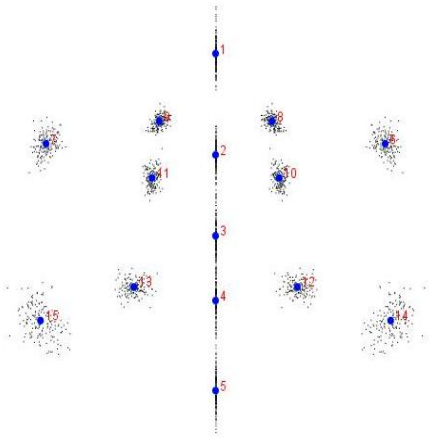

Figure 1. Anterior landmark configuration obtained after generalized Procrustes analysis. The figure shows the mean shape derived from the 15 aligned landmark coordinates of all study subjects after the effects of size, position, and rotation were removed.

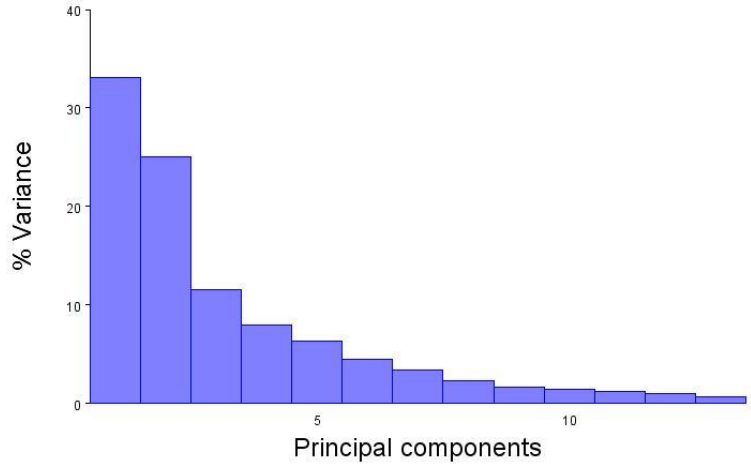

Figure 2. Eigenvalues obtained from principal component analysis (PCA) of anterior craniofacial shape.

Canonical variate analysis

Table 1. Canonical variate analysis of anterior craniofacial shape between CPD and non-CPD neonates

Comparison	Procrustes distance	Mahalanobis distance	P value (PD)	P value (MD)
CPD vs non-CPD	0.0326	1.0346	<0.001	<0.001

CPD, cephalopelvic disproportion; PD, Procrustes distance; MD, Mahalanobis distance. P values derived from permutation testing (1000 rounds).

Table 2. Procrustes ANOVA of anterior facial centroid size

Effect	SS	MS	Df	F	P value
Groups	344341.579779	344341.579779	1	11.85	0.0008
Individual	3022023.277838	29057.916133	104	1.60	0.0284
Residual	978146.265461	18113.819731	54	—	—

SS, sum of squares; MS, mean square; df, degrees of freedom; F, F-statistic.

Table 3. Procrustes ANOVA of anterior craniofacial shape

Effect	SS	MS	Df	F	P value
Groups	0.04256888	0.0032745295	13	4.44	<0.0001
Individual	0.99751429	0.0007378064	1352	2.98	<0.0001
Side	0.09169474	0.0070534412	13	28.53	<0.0001
Residual	0.68672883	0.0004891231	1404	—	—

SS, sum of squares; MS, mean square; df, degrees of freedom; F, F-statistic.

Table 4. Multivariate analysis of variance (MANOVA) of effects on anterior facial shape

Effect	Pillai's trace	P value
Groups	0.27	0.0042
Individual	8.97	0.0146

Values are Pillai's trace with associated parametric P values.

Table 5. Results of Independent Sample t-Test for confounding variables

	Non CPD(n=80) Mean ± SD	CPD(n=80) Mean ± SD	t-value	p-value
Birth Weight (kg)	2.52 ± 0.46	3.02 ± 0.35	-7.73	<0.0001
Maternal Age (years)	27.15 ± 4.21	27.89 ± 4.35	-0.86	0.393
Maternal Height (cm)	162.31 ± 6.18	161.67 ± 6.42	0.67	0.504
Parity	2.14 ± 1.32	2.21 ± 1.28	-0.26	0.799
Gestational Age (weeks)	39.11 ± 1.42	39.29 ± 1.36	-1.08	0.282
Birth Interval (years)	2.73 ± 1.11	2.82 ± 1.18	-0.47	0.636

DISCUSSION

The present study investigated anterior facial shape variation between neonates with cephalopelvic disproportion (CPD) and non-CPD controls using geometric morphometric techniques. The findings revealed significant differences in both facial shape and size between the two groups, suggesting that anterior facial morphology may play an important role in the fetopelvic relationship and the occurrence of CPD.

Principal component analysis showed that PC1 accounted for 33.136% of the total shape variation, PC2 explained 25.015%, and PC3 contributed 11.580%. Collectively, these three principal components explained approximately 69.73% of the total shape variation. This high cumulative percentage indicates that the majority of anterior facial morphological variation can be summarized by a few major axes of variation. According to Klingenberg,[19] when the first few principal components account for a substantial proportion of total variance, they represent biologically meaningful patterns of shape variation rather than random morphological noise. The high contribution of PC1 and PC2 in the present study suggests that specific aspects of anterior facial morphology differ consistently among the study groups.

Canonical variate analysis demonstrated significant separation between CPD and non-CPD neonates. The Procrustes distance (0.0326) and Mahalanobis distance (1.0346) were both statistically significant, with permutation P values of <0.001 for both measures. The significant distances observed indicate that anterior facial shape differs markedly between neonates with CPD and those without CPD. These findings suggest that specific configurations of facial and cranial landmarks are associated with the occurrence of CPD and may reflect fetal adaptations or morphological characteristics influencing labor outcomes.[20]

The significant canonical variate analysis results support the concept that craniofacial morphology contributes to the mechanics of childbirth. Variations in frontal cranial width, facial breadth, orbital configuration, and upper facial proportions may influence the dimensions and orientation of the fetal head during engagement and descent through the maternal pelvis. Previous studies have highlighted the importance of fetal cranial morphology in determining labor progression and the risk of obstructed labor.[21,22] Fetal head molding is an important biomechanical component of labor and can alter cranial dimensions and configuration as the fetal head passes through the maternal pelvis.[8,11,23,24] Recent three-dimensional MRI studies have demonstrated measurable deformation of the fetal skull during the second stage of labor, including changes in cranial dimensions and temporary overlap of cranial sutures; however, some of these changes may resolve shortly after birth.[20,25] Therefore, although the facial shape differences observed in the present study may reflect underlying biological variation, the possibility that transient delivery-related deformation contributed to some of the postnatal morphological differences cannot be completely excluded. Therefore, the significant discrimination observed in the present study further supports the potential value of facial shape as a marker of fetopelvic compatibility.

Centroid size analysis of the anterior view revealed significant differences between groups. The group effect was significant ($F = 11.85$, $P = 0.0008$), while the individual effect was also significant ($F = 1.60$, $P = 0.0284$). Centroid size represents the overall scale of the landmark configuration and serves as a size measure independent of shape.[16,25] The significant group effect suggests that neonates with CPD differ from controls not only in facial shape but also in overall craniofacial size. This finding may indicate that larger anterior facial dimensions contribute to difficulties in the passage of the fetal head through the maternal pelvis, thereby increasing the likelihood of CPD. The significant individual effect reflects expected biological variation among neonates but does not diminish the importance of the observed group differences.

Procrustes ANOVA results provided further evidence of significant facial shape variation. The group effect was highly significant ($F = 4.44$, $P < 0.0001$), while the individual effect was also highly significant ($F = 2.98$, $P < 0.0001$). A significant group effect indicates that CPD status is associated with systematic differences in anterior facial shape. The significant individual effect suggests the presence of natural morphological variability among neonates, which is expected in human populations. However, the stronger group effect indicates that the observed shape differences are not merely attributable to random individual variation. Similar observations have been reported in geometric morphometric studies where disease status or functional conditions produce distinct craniofacial shape patterns despite substantial individual variability.[19]

The MANOVA test of effects also confirmed significant multivariate differences in facial morphology. The group effect was significant (Pillai's trace = 0.27, $P = 0.0042$), while the individual effect was likewise significant (Pillai's trace = 8.97, $P = 0.0146$). Pillai's trace is considered one of the most robust multivariate statistics for morphometric data

because it remains reliable under varying data conditions.[20] The significant group effect indicates that CPD status accounts for a meaningful proportion of overall shape variation in the anterior craniofacial complex. The significant individual effect reflects normal biological diversity but does not obscure the clear morphological distinction between CPD and non-CPD groups.

These findings emphasize the value of geometric morphometric approaches in studying fetal craniofacial morphology. Traditional anthropometric measurements are limited to linear distances and may fail to capture complex spatial relationships among anatomical structures. In contrast, geometric morphometrics preserves the geometric relationships among landmarks and provides a more comprehensive characterization of biological form.[16,19] The significant findings obtained in the present study demonstrate the ability of geometric morphometrics to identify subtle but meaningful craniofacial differences associated with CPD.

Birth weight was significantly higher among neonates with CPD compared with controls ($p<0.0001$). This finding is biologically plausible because larger fetuses generally possess larger body and cranial dimensions, increasing the likelihood of mechanical difficulties during labor. Fetal macrosomia has long been recognized as a major risk factor for CPD, obstructed labor, and cesarean section.[26] The higher birth weights observed among CPD neonates therefore support the established relationship between increased fetal growth and labor complications.

In contrast, maternal age, maternal height, parity, gestational age, and birth interval did not differ significantly between CPD and non-CPD groups. These findings suggest that neonatal anthropometric characteristics may play a greater role in determining CPD risk within the study population than these maternal demographic variables. Although maternal height has frequently been reported as a predictor of obstructed labor and CPD, particularly in low-resource settings, its influence may vary according to population characteristics and nutritional status[27]. The absence of a significant association in the present study suggests that maternal stature alone may not adequately predict CPD among the study participants.

Limitations

The anterior facial geometric morphometric analysis in the present study was limited by its two-dimensional nature, which may not fully capture the complexity of three-dimensional craniofacial morphology. Furthermore, the anterior view provides limited information on anteroposterior cranial dimensions. The study was conducted in a single healthcare facility, which limits generalizability. Moreover, most of the study population was Hausa/Fulani that further limits generalization. In addition, CPD is a multifactorial condition involving both fetal and maternal factors; anterior craniofacial shape alone may not completely explain the occurrence of CPD. Future studies utilizing antenatal predictive models, three-dimensional imaging techniques, and larger, multi-center samples from different ethnic groups are recommended.

CONCLUSION

Anterior facial shape and size differed significantly between CPD and non-CPD neonates, demonstrating an association between anterior facial geometric morphometry and CPD status. Because facial images were obtained after delivery, these findings should be interpreted as an association rather than evidence that postnatal facial morphology independently predicts CPD, and further antenatal studies are required.

Conflict of interest: The authors have no conflict of interest to declare.

Authors' contribution: ISS: conception, study design, data acquisition, analysis, drafting; MAB: supervision, discussion, review and editing.

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