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Acta Orthopaedica 2023; 94: 594–599

Birthweight correlates to pubo-femoral distances and α angles in hip ultrasound of newborns at 6 weeks of age: a retrospective cohort study

Acta Orthopaedica

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Submitted 2023-09-13. Accepted 2023-11-05.

Background and purpose — There is inconsistency in the literature regarding the relationship between increased birthweight and risk of developmental dysplasia of the hip (DDH). We aimed to investigate the correlation between birthweight and pubo-femoral distance (PFD), as well as Graf's α angle in newborns undergoing hip ultrasound examination at 6 weeks of age.

Patients and methods — Basic newborn characteristics and ultrasound measurements were retrospectively collected during a 1-year study period. We excluded multiple births, newborns born at less than 37 gestational weeks, and incomplete information. Simple and multiple linear regression analyses were performed to evaluate the correlation of birthweight and PFD, and, second, birthweight and α angles including a stratified regression analysis investigating the potential effect modification of sex.

Results — 707 newborns (1,414 hips) were included. Mean birthweight was significantly higher for male newborns ($P < 0.001$). Increased birthweight was positively correlated to PFD values (crude coefficient 0.21, 95% confidence interval [CI] 0.10–0.32) and the correlation was still present after adjusting for sex, family history, and breech presentation (adjusted coefficient 0.18, CI 0.07–0.29). The stratified α angle model for the males was significant for both the crude coefficient (–0.73, CI –1.28 to –0.19) and the adjusted (–0.59, CI –1.15 to –0.03), and also for the females (crude coefficient –1.14, CI –1.98 to –0.31 and adjusted coefficient –1.15, CI –1.99 to –0.31).

Conclusion — We found that increased birthweight positively correlated to PFD, and negatively correlated to α angle, but this was not of clinical significance.

Developmental dysplasia of the hip (DDH), a disorder due to abnormal development of the acetabulum with or without hip dislocation, is the most common pediatric hip disorder [1]. The etiology of DDH is complex, thus multiple "risk factors" are used as referral criteria, and include breech position, female sex, and positive family history, for follow-up hip ultrasound in DDH screening [2]. Oligohydramnios, multiple births, and birthweight have also been proposed as increasing the risk of DDH [3-5].

The Graf ultrasound screening method in newborns for DDH is widely implemented [6] but requires training [7]. The Graf ultrasound method measures the α-angle. The pubo-femoral distance (PFD) was proposed as an accessible supplement to the α-angle [8]. PFD is a less complex ultrasound measurement for DDH screening supported by a high sensitivity and specificity for DDH [9] and is reliable when used by radiologists or technicians with limited experience in ultrasound [10].

There is inconsistency in the literature as to the relationship between birthweight and risk of DDH. Some have reported no or increasing correlation of birthweight and DDH [11,12]. Others found that increased birthweight was negatively correlated to α angles in hip ultrasound performed 7 days after birth, but only in females [13].

We aimed to investigate the correlation between birthweight and PFD in DDH ultrasound examinations. Second, we wished to investigate whether increased birthweight is correlated to α angle in DDH ultrasound, and the influence of sex on this correlation.

DOI 10.2340/17453674.2023.26188

Patients and methods

Study design

This was a retrospective observational study. Reporting follows the STROBE guidelines for reporting on observational studies [14].

Participants

We included newborns born at Aarhus University Hospital from October 2021 to October 2022 within 37–42 gestational weeks who were referred for follow-up hip ultrasound based on presence of risk factors (breech presentation, family history, multiple births, oligohydramnios, or clubfeet), positive clinical examination, a PFD above 5.1 mm or a combination of these factors. PFD as a referral criterion was introduced as part of the Danish Hip Screening project (DHS) at Aarhus University Hospital. Referred newborns received specialized hip ultrasound, ideally within 6 weeks or 2 weeks if clinical instability was detected upon screening.

From patients' files we included birthweight, gestational age, sex, age at ultrasound examination, and hip ultrasound measurements. We excluded multiple births as newborns from multiple births are usually lighter, as well as premature newborns born at less than 37 gestational weeks. Newborns with incomplete data, defined as missing information on one or more variables, were also excluded.

Ultrasound examination

Hip ultrasound examination of referred newborns was made by 1 of 3 senior musculoskeletal radiologists experienced in pediatric hip ultrasound. α angles were obtained according to the methods described by Graf [6] (Figure 1a), and PFD measurements, defined as the minimal measurable distance between the medial femoral epiphysis and the ossified pubic bone while applying lateralizing stress to the hip, according to the methods described by Treguier [8] but with the child in the lateral examination position (Figure 1b). Ultrasound was performed using a high-frequency linear transducer (Canon Aplio i800; Canon Medical Systems, Tokyo, Japan).

Variables

Variables under investigation were sex (male/female), birthweight (gram), breech presentation (yes/no), family history of DDH (yes/no), positive clinical examination (yes/no), oligohydramnios (yes/no), congenital foot deformities (yes/no), referred based on primary PFD > 5.1 mm at first week after birth (yes/no), gestational age (days), and age at examination (days). Ultrasound measurements at 5–6 weeks were α angle (°) and second PFD measurement (mm), which were used for the correlation analysis.

Statistics

For descriptive statistics, continuous variables (birthweight, gestational age, age at examination, α angles, and PFD measurements) were reported as arithmetic mean and standard deviation (SD). For categorical variables (positive clinical examination, breech presentation, family history of DDH, oligohydramnios, congenital foot deformities), the number of observations and the relative percentages were reported. PFD and α-angle measurements from the follow-up hip ultrasound were used for the statistical analysis. As a first step, Pearson's chi-square test and Fisher's exact test (the latter when the expected count was < 5) were performed for categorical variables and t-test for the continuous variable to estimate possible differences between female and male newborns.

In a second step, simple linear regression analysis was performed to evaluate the potential association of birthweight (independent variable) and PFD (dependent variable), and, second, the potential association of birthweight (independent variable) and α angle (dependent variable). Multiple regression analysis was performed to evaluate the above-mentioned potential associations adjusted for 3 well-known risk factors (sex, breech presentation, and family history of DDH). As a third step, stratified regression analysis in male and female newborns was performed for birthweight and α angle, due to potential effect modification of sex between these 2 variables. The coefficient results are presented with 95% confidence interval (CI) and scatter plots were created to present the regression analysis results. To account for the bilaterality of data, a sensitivity analysis was performed using mixed-model analysis for all the previously mentioned simple and multiple linear regressions. As the analysis was not significantly different, independence between sides was assumed and the linear regression results are reported for simplicity.

Normal distribution of birthweight, PFD, and α angle measurements were inspected using QQ plots. A P value < 0.05 was considered statistically significant. Statistical analyses were performed using Stata version 17.0 (StataCorp, College Station, TX, USA).

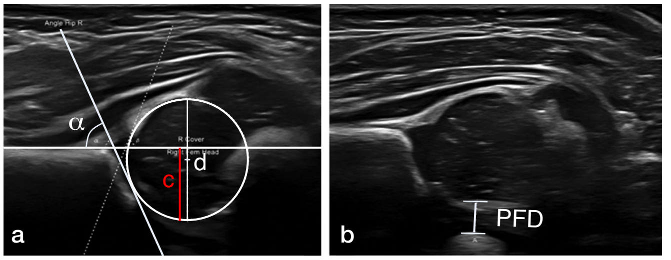

Figure 1. a. Ultrasound image of a newborn hip with annotated α angle and femoral head coverage (c/dx100) measurements, obtained according to the methods described by Graf [6] and Falliner [26].
b. Ultrasound image of a newborn hip with annotated PFD measurement, obtained according to the methods described by Tréguier et al. [8] but with the child in the lateral examination position.

Ethics, registration, data sharing, funding, and disclosures

Written consent for data acquisition (prospectively collected data of PDF and α-angle measurements, as well as retrospec-

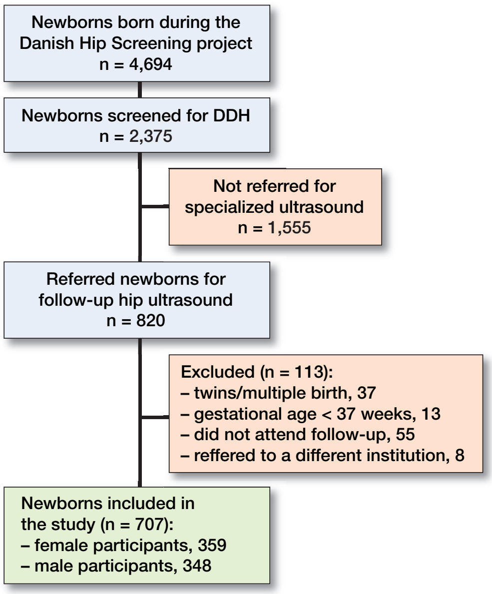

Figure 2. Flowchart of patients included in the study.

tive data such as birthweight) was obtained from both parents of the included newborns at the referred follow-up ultrasound. The study, the written patient information, and the protocol was approved by the institutional ethical committee (Ref no: N-20200051). This study was funded by the Independent Research Fund Denmark Grant no. 1030-00366B, Gigtforeningen, Health Professional Fund at Aarhus University, and Dagmar Marshall Fund. The authors declare no conflict of interest. Complete disclosure of interest forms according to ICMJE are available on the article page, doi: 10.2340/17453674.2023.26188

Table 1. Baseline characteristics. Values are mean (SD) and minimum–maximum

Descriptive characteristics	Female n = 359	Male n = 348	Total n = 707	P value
Birthweight (g)	3,530 (439)	3,689 (475)	3,608 (463)	< 0.001
range	2,350–4,930	2,330–5,265	2,330–5,265	
Gestational age (days)	281 (8.1)	281 (8.5)	281 (8.3)	0.7
range	259–296	259–296	259–296	
Age at examination (days)	36 (11.3)	37 (12.4)	37 (11.9)	0.3
range	5–87	4–121	4–121	
Angle α (°), right	66 (4.7)	67 (3.3)	66 (4.1)	< 0.001
range	46–77	54–76	46–77	
Angle α (°), left	65 (5.3)	67 (3.7)	66 (4.7)	< 0.001
range	41–83	55–82	41–83	
PFD (mm), right	4.0 (1.06)	4.0 (0.75)	4.0 (0.92)	0.7
range	1.6–9.9	2.0–6.5	1.6–9.9	
PFD (mm), left	4.0 (1.26)	3.9 (0.75)	3.9 (1.04)	0.4
range	1.5–11.2	2.0–6.3	1.5–11.2	

T-test was used to estimate possible differences between female and male newborns
PFD = pubo-femoral distance.

Table 2. Risk factors of patients included. Values are the number of observations and the relative percentages

Risk factors	Female n = 359	Male n = 348	Total n = 707	P value
Positive clinical examination	40 (11)	34 (9.8)	74 (11)	0.6
Breech presentation	55 (15)	43 (12)	98 (14)	0.3
Family history of DDH	44 (12)	46 (13)	90 (13)	0.7
Oligohydramnios	6 (1.7)	5 (1.4)	11 (1.6)	0.8
Congenital foot deformities	0 (0.0)	2 (0.6)	2 (0.3)	0.2
Referred based on primary PFD screening	257 (72)	253 (72)	510 (72)	0.7

Pearson's chi-square test and Fisher's exact test (the latter when the expected count was < 5) were performed to estimate possible differences between female and male newborns.
PFD = pubo-femoral distance.

Results

Study population

Based on 4,694 newborns born during the 1-year study period, a cohort of 2,375 newborns (51%) participated in the Danish Hip Screening project following consent from their parents. Of these, 820 newborns (34%) were referred for ultrasound (Figure 2). 55 did not attend. Furthermore, 37 were multiple births and 13 had a gestational age < 37 weeks, leaving 707 newborns (1,414 hips) for inclusion in our study with equal distribution of males and females (348; 359). 431 newborns were referred based on their first PFD measurement witho having any other risk factor. Mean birthweight was significantly higher for male newborns at 3,689 g (SD 475) vs. 3,530 g (SD 439) ($P < 0.001$), while the total mean age at examination was 37 days (SD 11.9) (Tables 1 and 2). There was no difference between the 2 groups in the PFD measurements (PFD right side $P = 0.7$, PFD left side $P = 0.4$). The mean α-angle measurements for both left and right hip were significantly lower for female newborns ($P < 0.001$). Considering the risk factors, there was no difference between the groups (Table 2).

Birthweight and PFD

Increased birthweight was positively correlated to PFD values (crude coefficient 0.21, CI 0.10–0.32) and this correlation was still present when adjusting for sex, family history, and breech presentation (adjusted coefficient 0.18, CI 0.07–0.29). A regression model and a scatter plot were established according to the following: PFD = 3.27 (mm) + 0.18 (mm) × birthweight (kg) (Figure 3).

Birthweight and α angle

Linear regression analyses showed a significant negative correlation between birthweight and α angles (crude coefficient –0.56, CI –1.06 to –0.07, $P = 0.03$), which was still present after adjusting for known risk factors and sex (adjusted coefficient –0.88, CI –1.38 to –0.38, P = 0.001), with sex being the largest contributor for this adjusted difference (Table 3). The regression analysis stratified by sex showed a significantly negative correlation between increased birthweight and α angles for both sexes but indicated a larger effect for females (Table 3). As a result, a regression model was established according to the following: females α angle = 69.3 – 1.15 × birthweight (kg), and males α angle = 69.0 – 0.59 × birthweight (kg). Figure 4 presents the scatter plot of these models.

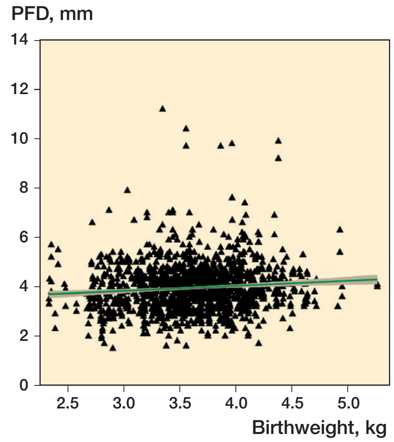

Figure 3. Scatter plot of birthweight and PFD values with fitted linear regression model on the effect of birthweight to PFD measurement (n = 707). PFD = pubo-femoral distance. The green line shows the fitted values, and the grey zone represents the CI.

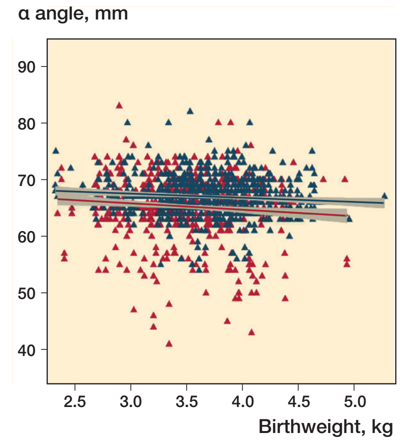

Figure 4. Scatter plot of regression model on the effect of birthweight to α-angle measurement for female (red) (n = 359) and male (blue) (n = 348) newborns. The red and blue lines show the fitted values, and the grey zones represents the CI.

Table 3. Regression analysis indicating the effect of birthweight on PFD and α angle

Linear regression for	Coefficient (CI)	P value
PFD and birthweight (per kg)		
Crude	0.21 (0.09 to 0.32)	< 0.001
Adjusted for sex	0.22 (0.11 to 0.34)	< 0.001
Adjusted for family history	0.18 (0.08 to 0.29)	0.001
Adjusted for breech presentation	0.20 (0.09 to 0.31)	< 0.001
Adjusted for all above [a]	0.18 (0.07 to 0.29)	0.002
α angle and birthweight (per kg)		
Crude	–0.56 (–1.06 to –0.07)	0.03
Adjusted for sex	–0.93 (–1.42 to –0.43)	< 0.001
Adjusted for family history	–0.53 (–1.03 to –0.03)	0.04
Adjusted for breech presentation	–0.57 (–1.07 to –0.07)	0.03
Adjusted for all above [a]	–0.88 (–1.38 to –0.38)	0.001
α angle and birthweight (per kg): male		
Crude	–0.73 (–1.28 to –0.19)	0.008
Adjusted for family history and breech presentation	–0.59 (–1.15 to –0.03)	0.04
α angle and birthweight (per kg): female		
Crude	–1.14 (–1.98 to –0.31)	0.007
Adjusted for family history and breech presentation	–1.15 (–1.99 to –0.31)	0.007

[a] family history, breech presentation, and sex

Discussion

We aimed to investigate the correlation between birthweight and pubo-femoral distance (PFD), as well as Graf's α angle in newborns undergoing hip ultrasound examination at 6 weeks of age. We found a positive correlation between increased birthweight and PFD measurements of newborns screened for DDH at 6 weeks of age, regardless of sex. Birthweight was found to be negatively correlated to α angles for both females and males. However, the correlations were too small to be considered clinically significant.

Although several risk factors have been examined in relation to DDH, birthweight still remains a controversial factor. The meta-analysis of De Hundt et al. [2], based on 4 studies [15-18], reported low birthweight (< 2,500 g) as being protective. This finding supported the concept of intrauterine crowding, as DDH may develop in part due to limited space for the fetus inside the uterus. 3 additional studies [11,19-20] have presented high birthweight (> 4 kg) as a risk factor, and Falliner et al. [21] found that children with dysplastic hips had markedly higher birthweight than children with normal hips. The cohort study by Schams et al. [20] suggested low birthweight as a protective factor. Hanratty et al. [12] found no correlation between increased birthweight and risk of DDH.

However, a dichotomous DDH diagnosis as an outcome measurement, while clinically relevant, might not be sensitive enough to show the possible contribution of birthweight, and as a result the use of α-angle measurement or PFD as an outcome seems more suitable for the investigation of birthweight's effect. The positive correlation of increased birthweight to PFD values found in our study may partly be explained by the fact that the PFD is an absolute distance measurement that increases with the size of the child, similarly to the increase that is seen when the child ages [22]. But as PFD is highly sensitive for DDH [9], increased birthweight may be perceived as an effect modifier on the relationship between PFD and hip dysplasia. These findings may also indicate that a cut-off value for PFD should be assessed on a semi-individual basis, taking the child's size (i.e., birthweight) into account, in order to decrease false-positive referrals based on PFD measurements.

Orak et al. [13] and Kolb et al. [23] used α-angle measurements as a main outcome. The findings of Kolb et al. seem to be in agreement with our results, as their univariate regression analysis showed a significant negative influence of increased birthweight per 100 grams on the α angle (coefficient –0.071, CI –0.096 to –0.046) [23]. Orak et al. found that increased birthweight negatively affects α angles in hip ultrasound but only for female newborns, without reporting the exact results of linear regression analysis for males. Our findings suggest that increased birthweight has a negative effect on α angle measurements for both sexes.

Orak et al. [13] performed the ultrasound in the first after birth and Kolb et al. [23] in the first 2 postnatal weeks, which may entail a higher prevalence of false-positive or false-negative results due to immaturity of the hips. The newborns included in this study were screened at 5–6 weeks post-partum, as we aimed to investigate the persistent effect of birthweight on PFD and α-angle measurements. In addition to the previous studies, these results highlight that maturity of the hips does not seem to change the correlation between birthweight and α angles.

Roposch et al. [24] proposed a prediction model generating absolute predicted risk of DDH within 8 weeks postpartum on the basis of each at-risk newborn's individualized clinical risk profile. The risk model includes 4 predictors: female sex, first-degree family history of DDH, birthweight > 4,000 g and abnormal examination of hip. This prediction model suggests increased birthweight is regarded as a component of the total risk of DDH for each newborn rather than a stand-alone referral criterion, as a correlation between DDH status and increased birthweight cannot be detected. While the study by Hanratty et al. [12] suggests that increased birthweight does not sufficiently increase the risk associated with increased birthweight, to warrant its use as a referral criterion birthweight may be considered as a contributing factor to the overall DDH risk profile of newborns. This suggestion is supported by the existing literature, as well as by the results of our study.

Strengths

First, this is the first study that examined the influence of increased birthweight on PFD measurements, as well as on α-angle measurements in hip ultrasounds of newborns screened for DDH at 6 weeks postpartum. Second, we included ultrasound data of a non-selected cohort of newborns with family history of DDH and breech presentation performed by well-trained and experienced senior musculoskeletal radiologists. In contrast, Orak et al. [13] excluded newborns with these risk factors, which makes their population even more selective. In addition, premature newborns were defined as newborns born alive before 37 gestational weeks [25], while Orak et al. [13] included 38–42-week-old newborns and Kolb et al. [23] included both premature and full-term newborns.

Limitations

First, the results cannot be generalized because the population consist of screened newborns with risk factors and/or a pathological primary PFD measurement. However, as the PFD measurement was used as a stand-alone referral criterion, 61% of the included newborns had no risk factors for DDH, which makes the present results more generalizable than previous reports from selective screening programs that exclusively included children who had a risk factor for DDH. Second, no interobserver evaluation was performed on ultrasound examinations.

Conclusions

Increased birthweight was positively correlated to PFD measurements for both female and male at-risk newborns, and negatively correlated to α-angle measurements in newborns screened for DDH at 6 weeks of age, regardless of sex. The findings seem not to be of clinical significance due to small effect size. Increased birthweight may only be relevant in the context of a multiple-factor risk profile for DDH.

Study design and conception: all co-authors. Data acquisition: MBH, MH, NL, and HCH. Data analysis: MT and HCH. Writing: MT. Review: all authors.

Handling co-editor: Ilkka Helenius
Acta thanks Sophie Moerma, Michael Sussman, and an anonymous reviewer for help with peer review of this manuscript.

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