Original Clinical Article

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The potential role of the Alsberg angle as a predictor of lateral growth disturbance of the capital femoral epiphysis in children with developmental dysplasia of the hip treated by closed reduction

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Abstract

Purpose Early diagnosis and prevention of lateral growth disturbance of the capital femoral epiphysis is challenging after treatment for developmental dysplasia of the hip (DDH). The aim of the study was to evaluate the radiographic changes of the Alsberg angle (AA) in normal children and those with DDH, and to assess the role of AA as a potential predictor of lateral growth disturbance of the capital femoral epiphysis.

Methods AA was measured on the anterior-posterior pelvic radiographs of 1000 normal children ranging in age from one to ten years and in 66 children (92_hips) with DDH treated by closed reduction (CR). A comparative analysis was performed.

Results In the normal children, mean AA decreased linearly with age, from 76° at age one year to 65° at age ten years, irrespective of gender and laterality. In children with DDH, the average AA was 81.5°(SD 3.9°; 74° to 87°) prior to CR; it was 75.9° (SD 4.5°; 68° to 83°) in normal children of the same age ($p < 0.001$). Among the 42 children (64 hips) with successfully and uneventfully treated DDH, AA reached normal values between the ages of five and six years. In contrast, children with lateral growth disturbance of the proximal femur physis (24 children, 28 hips) showed significantly higher AA values in comparison with the age-matched controls.

Conclusion In DDH patients with successful CR, AA could be expected to match normal values in children between the ages of five and six years. On the other hand, AA can be used as an early predictor for lateral growth disturbance of the capital femoral epiphysis.

Level of Evidence: Level III

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Keywords: Alsberg angle; developmental dysplasia of the hip; avascular necrosis; lateral growth disturbance; closed reduction

Introduction

Avascular necrosis (AVN) of the proximal femur epiphysis is a potential complication following the treatment of developmental dysplasia of the hip (DDH). Kalamchi and MacEwen[1] identified four types of AVN: type I is characterized by selective femoral head epiphysis involvement; type II is characterized by lateral growth disturbance of the proximal femoral epiphysis; type III has typical central proximal femur physis involvement; and type IV is characterized by the involvement of the proximal femur epiphysis and physis.

Type II is the most frequent type of AVN.[1,2] In type II, the reduced growth rate and the presence of a lateral bone bridge across the physis lead to progressive horizontalization and/or lateral tilting of the physis with subsequent femoral head lateral tilt, hip valgus and hip subluxation. However, these signs tend to become visible mostly around a pubertal growth spurt; thus, early diagnosis and prevention is challenging.[2-4]

One common parameter that measures the inclination of the proximal femur physis is the angle between a line joining the innermost and the outermost end of the proximal femoral physis and the Hilgenreiner's line (HE angle). However, the position of the lower extremity can influence the accuracy of the HE angle measurement.[5]

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The Alsberg angle (AA), measured on anteroposterior (AP) radiographs, is the angle between the axis of the femur shaft and the proximal femur physis; it is an important anatomical parameter of the proximal femur because it measures the inclination of the proximal femur physis. It has been shown that decreased AA may lead to proximal femur varus, while increased AA may lead to valgus. Moreover, changes in AA can affect the mechanical forces acting on the proximal femur epiphysis.[6] Therefore, it is possible that progressive horizontalization of the proximal femoral physis and AA increase following closed reduction could be related to the occurrence of lateral growth disturbance of the proximal femoral epiphysis.

The primary aim of the present study was to evaluate the radiographic changes of AA during growth in normal children (normative data) in comparison with children with DDH managed by closed reduction and spica cast immobilization. The secondary aim of the study was to assess if there is a correlation between AA changes and onset of lateral growth disturbance and to elucidate the role of AA as a potential predictor of lateral growth disturbance of the capital femoral epiphysis in children with DDH treated by closed reduction.

Materials and methods

This study was designed to evaluate the radiographic changes of AA in normal children and in children with DDH managed by closed reduction. The institutional review board of the authors' institution approved the study (approval number: 2017PS082K).

Healthy children, aged one to ten years

A cohort of 1000 healthy children (age range: one to ten years) underwent AP pelvis radiography in the supine position. Acceptance criteria for this study required the subjects to be between one and ten years of age at the time of radiographic examination. All patients had to be healthy with no history of fracture or surgery, no systemic disease affecting the quality and/or the structure of the bone, no localized bone disease or deformity secondary to tumour, infection, congenital abnormality and/or no prior surgery.

Patients were divided into ten groups of 100 patients each. Group 1 included patients up to one year of age, Group 2 included patients between one and two years of age, Group 3 included patients between two and three years of age; this age increment continued up to Group 10, which included patients between nine and ten years of age.

All patients underwent AP radiography of the pelvis after both parents gave their approval and signed the informed consent form. A total of 614 male and 386 female patients were included in the study.

Children with DDH

From January 2006 to December 2010, 112 patients with DDH, ranging in age from six to 32 months, were managed by closed reduction and spica cast immobilization at our institution, and the outcomes were retrospectively evaluated. Only patients with complete medical records and imaging data were included in the study. Moreover, to be included in this retrospective review, the patients had to have no less than seven years of follow-up with at least one AP pelvis radiograph per year.

Patients with a concomitant neuromuscular condition, pathological dislocation of the hip, surgical treatment, incomplete medical records and/or imaging data and a follow-up less than seven years were excluded from the analysis. AVN type was rated according to Kalamchi and MacEwen's[1] (K-M) classification; the Severin classification system[7] was used to evaluate the outcome.

Among the 112 patients with DDH treated by closed reduction, 15 cases were excluded due to short follow-up (13.4%), ten cases were excluded due to poor outcome (Severin type III or type IV at the last follow-up visit; 8.9%), nine cases were excluded due to K-M type III or IV (8%), eight cases were excluded due to additional surgical procedures (open reduction; 8%) and four cases were excluded due to incomplete medical records and/or imaging data (3.6%).

A total of 66 patients (58.9%) with a mean follow-up time of 8.4 years (7.2 to 11.8) were available for analysis, including 42 Severin grade I or grade II patients (eight male, 34 female; five right side, 15 left side, 22 bilateral) with a mean age at initial treatment of 14 months (7 to 32) and 24 patients with lateral growth disturbance of the proximal femoral epiphysis (five male, 19 female; six right side, 14 left side, four bilateral) with a mean age at initial treatment of 16 months (9 to 26).

Radiographic measurements

AA was measured on the AP pelvis radiographs of the normal children (n = 1000) and the children with DDH (n = 66) using a picture archive and communication system (Neusoft, Shenyang City, China).

AA is the angle between the axis of the femur shaft and a line joining the innermost and the outermost end of the proximal femoral physis. The axis of the femoral shaft was determined by randomly selecting two sections on the femoral stem, and the connection of the centre points of those two sections was defined as the axis (Fig. 1).

Statistical analysis

Statistical analysis was performed using SPSS11.5 software (SPSS Inc., Chicago, Illinois). A two-way analysis of variance (ANOVA) was used to compare the difference of AA between groups of normal children, moreover,

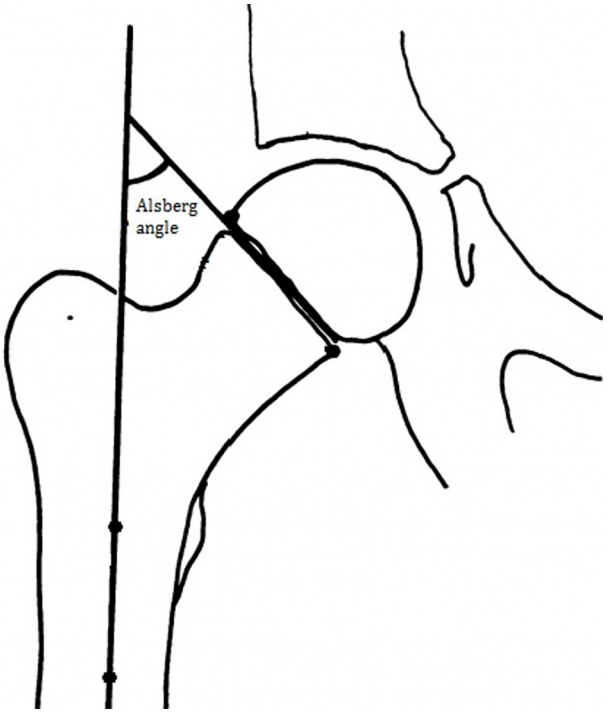

Fig. 1 The Alsberg angle.

Table 1 Intra- and interobserver agreement among the raters for Alsberg angle

	Alsberg angle		
Raters	ICC	95% CI	p-value*
M1–M1	0.986	0.985–0.987	< 0.001
M1–M2	0.860	0.836–0.891	< 0.001
M1–M3	0.978	0.975–0.980	< 0.001
M2–M3	0.871	0.850–0.890	< 0.001

* Pearson's correlation coefficient was used to evaluated the intra- and inter-observer reliability.
ICC, interclass correlation coefficient; CI, confidence interval

mixed-model pairwise multiple comparisons were applied to analyze the difference of AA between the left and right side. Likewise, three-way ANOVA was performed to analyze the difference of AA between hips with or without lateral growth disturbance and normal hips. Moreover, ten cases were randomly selected from the normal children from each age strata (1 to10); a total of 100 selected cases (200 hips) were used to test for measurement reliability (conducted by RG, FC and SL). Intra- and intergroup reliability were tested using Pearson's correlation coefficient and intraclass correlation coefficient (ICC). An ICC > 0.75 was considered perfect consistency, an ICC between 0.40 and 0.75 was considered to be fair, and an ICC < 0.40 was considered to be poor. A p-value < 0.05 was considered to be statistically significant.

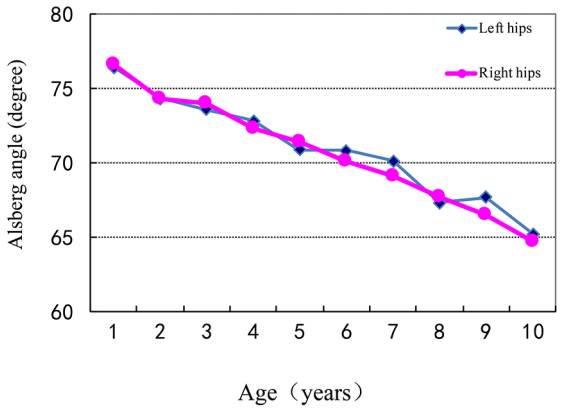

Fig. 2 Changes in the Alsberg angle based on age in normal children (left side and right side).

Table 2 Changes in the Alsberg angle based on age in normal children (left side and right side); values are expressed in degrees (°)

	Left side		Right side	
Age, yrs	Mean	SD	Mean	SD
1	76.47	3.41	76.66	4.57
2	74.37	4.45	74.36	4.64
3	73.58	4.15	73.99	4.65
4	72.87	3.99	72.29	4.80
5	70.90	5.68	71.47	5.40
6	70.86	4.52	70.15	5.10
7	70.16	5.12	69.15	5.09
8	67.34	5.16	67.73	4.38
9	67.68	3.95	66.55	4.88
10	65.22	4.12	64.69	4.26

Results

Table 1 shows the intra- and intergroup reliability results. The minimum ICC was 0.86 (p < 0.001), indicating perfect intra- and intergroup correlation. In the normal children, AA decreased linearly with age (Fig. 2, Table 2), and no statistically significant difference was found between the left side and the right side (F = 1.24, p = 0.266) or between male and female cases (left side, p = 0.072, right side, p = 0.342).

In children with DDH, the mean AA was 81.5° (SD 3.9°; 74° to 87°) prior to closed reduction; it was 75.9° (SD 4.5°; 68° to 83°) in the normal children of the same age (p < 0.001).

We observed that, among the 42 children (64 hips) with successfully treated DDH (stable and concentric reduction) and an uneventful postoperative course, AA reached normal values by the age of five to six years; at the last follow-up visit, the mean AA was 68.4° (SD 6°; 56° to 88°), which is similar to the AA of the age-matched normal children.

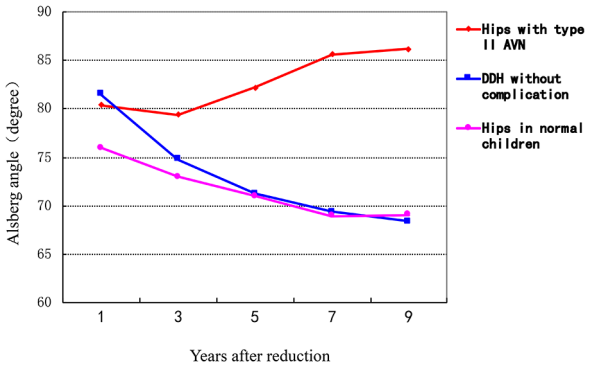

Fig. 3 Changes in the Alsberg angle in children with developmental dysplasia of the hip (DDH) managed by closed reduction and spica cast immobilization *versus* normal children (AVN, avascular necrosis).

In contrast, it was observed that, among children developing lateral growth disturbance of the proximal femoral epiphysis (24 children, 28 hips), the average AA was 80.4° (SD 4.6°; 74° to 86°) prior to closed reduction; it was 86.2°(SD 5.5°; 70° to 97°) at the last follow-up visit, showing an opposite trend in comparison with the normal children and the children with DDH that were successfully treated (Fig. 3).

Discussion

The present study found that, in children with DDH with successful closed reduction (Severin type I or type II) and without postoperative complications, AA should be expected to match normal values by five to six years of age. However, if AA remains unchanged or stays above the normal values for children of the same age, disturbed growth of the lateral capital epiphysis should be suspected. Consequently, AA could be used as an early predictor for lateral growth disturbance of the proximal femur in children undergoing closed reduction for DDH.

AA is an important anatomical parameter of the proximal femur. It measures the inclination of the proximal femoral physis and it can provide useful information about the development of the proximal femur; in particular, a decrease in the AA can lead to hip varus while an increase can lead to hip valgus. If the femur shaft is used as a reference, AA is not affected by the abduction or adduction of the hip joint. Oguz[8] reported that in adults the normal AA value is about 40°, and there is a nearly constant difference between the angle of inclination (neck-shaft angle) and the AA. However, normative AA data in normal children have not been reported.

In this study, we found that the AA decreases linearly from birth (mean 76°) to age ten years (mean 65°), irrespective of sex and laterality. It is possible that this developmental pattern could be related to upright walking and related biomechanics, since the direction of the physis at both ends of the femur tends to be perpendicular to the direction of the vertical compressive stress.[9]

It has been shown that changes in AA can affect the mechanical forces acting on the proximal femur physis.[9,10] In particular, AA reduction is associated with increased shear forces on the physis with subsequent risk of developing slipped capital femoral epiphysis (SCFE) or femoral neck fracture. Likewise, Morris et al[11] noted that increasing capital femoral epiphyseal extension may bring physeal stability and reduce the risk for SCFE. Thus, the evaluation of the direction of the proximal femur physis has been reported to be an important reference for the contralateral prophylactic fixation in unilateral SCFE[12,13] and for the outcome of varus osteotomy.[14] Novais et al[15] previously determined reference values for epiphyseal tilt and epiphyseal angle in asymptomatic patients aged 12 to 18 years of age by using radially reformatted CT imaging; they could not identify any age- or sex-specific variation for the epiphyseal tilt in the superior (coronal) and anterior (axial) planes although male patients were found to have a decreased epiphyseal angle with increasing age in the anterosuperior plane. Such a finding corresponds to an

Fig. 4 Anteroposterior pelvis radiographs showing the changes in the Alsberg angle in a 17-month-old girl with bilateral developmental dysplasia of the hip treated by closed reduction **(a)**. The patient developed type II growth disturbance. At the age of six years, the Alsberg angle was 76° on the left side and 74° on the right side **(b)**; at the age of nine years, it was 78° on the left side and 75° on the right side **(c)**; at the age of 12 years, it was 82° on the left side and 79° on the right side **(d)**.

increase in epiphyseal extension and may serve as reference for future studies investigating SCFE as well as the development of femoroacetabular impingement.

Normal AA values in children ranging in age from one to ten years can be used as reference values by the surgeon dealing with proximal femur disorders of different etiologies (Table 2).[12-14]

Early identification of lateral growth disturbance of the proximal femoral epiphysis in patients with DDH treated by closed reduction is critical for early identification and monitoring of potential developmental malformations of the proximal femur and early intervention.[16-21] Oh et al[22] divided lateral growth disturbance into two subtypes based on the shape of the proximal femur at the maturation phase: type A, with continuous Shenton line, proximal femur varus and good prognosis (Severin type 1 or type 2 hip) and type B, discontinuous Shenton line, proximal femur valgus and poor prognosis (Severin type 3 and type 4 hip). However, no previous study has reported on the early prediction of lateral growth disturbances, which can potentially lead to the secondary 3D deformity of the proximal femur.[23] We assumed that AA can be used for early prediction of lateral growth disturbance by observing the evolution of the inclination of the physis as seen on AP pelvis radiographs after closed reduction. However, these radiological signs in young children may not be obvious because they begin to appear gradually around the age of nine years.[22,24] McGillion and Clarke[18] reported on 11 patients with increasing inclination angle of the proximal femur physis that were treated by proximal femoral hemi-epiphysiodesis who were followed up until skeletal maturity. In seven out of 11 hips, hip valgus improved significantly; one hip did not show any sign of valgus improvement while it worsened in the remaining two hips. They concluded that the change in the inclination angle of the proximal femoral physis is an important indicator of early diagnosis for lateral growth disturbance, and that hemi-epiphysiodesis can effectively prevent the occurrence of secondary deformity. However, it is a 2D treatment option for a 3D deformity and, therefore, it should be applied with caution.

Untreated patients with a dislocated hip have a higher AA than age-matched normal children. This finding can be related to the abnormal biomechanical forces acting on the proximal femur physis of dislocated hips. Interestingly, we found that, following concentric and stable reduction and restoration normal biomechanics of the hip joint, the physis gradually becomes perpendicular to the direction of the vertical compressive stress.[9] In particular, in DDH patients undergoing successful closed reduction (Severin type I or type II) who did not develop any complications, AA progressively reaches normal values at five to six years of age (Table 2, Fig. 3). However, if patients develop lateral growth disturbance of the proximal femoral epiphysis following closed reduction, the AA remains unchanged or increases above normal values for children of the same age (Table 2, Fig. 4).

We encountered some limitations in the analysis of our results. The first limitation is the retrospective nature of our research with inevitable selection bias. Although this source of bias might not have had a direct influence on the result, there was no specific randomization or sequence generation. At the same time, the control group was a majority male cohort whereas hip dysplasia is more frequent in female children; however, no significant difference could be identified between boys and girls allowing us to use a majority male control group. Moreover, although we used AA to measure the amount of inclination of the proximal femoral physis to overcome the limits of using HE angle, the position of the lower extremity still had to be monitored. The sensitivity and specificity of early diagnosis of lateral growth disturbance using AA still required a larger sample size and prospective studies to confirm the present findings. On the other hand, due to the fact that all AP pelvis radiographs were taken in the supine position for all ages of the patients, it is possible that some bias of measurement may have occurred. Furthermore, AA represents a 2D measurement for a 3D deformity not allowing a comprehensive evaluation of the deformity.

In summary, in normal children, AA decreases linearly from age one year to age ten years, irrespective of gender or laterality. In contrast, AA is above the normal values for age in patients with DDH. If the hip is concentrically reduced and the patient does not develop lateral growth disturbance of the proximal femoral epiphysis, AA progressively returns within normal limits around five to six years of age, and it develops normally thereafter. However, if AA remains unchanged or increases following closed reduction, growth disturbance of the lateral portion of the proximal femur physis should be suspected. In this respect, AA could be used as an early predictor of lateral growth disturbance in children with DDH managed by closed reduction, thus facilitating early surgical intervention in selected cases.

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COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

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ETHICAL STATEMENT

Ethical approval: This research involved human participants. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Medical Ethics Committee of the authors' institution (approval number: 2017PS082K).

Informed consent: Written informed consent was obtained from both parents of each participant.

ICMJE CONFLICT OF INTEREST STATEMENT

None declared.

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AUTHOR CONTRIBUTIONS

RG: Data collection, Performed measurements, Manuscript preparation.
FC: Study design, Manuscript preparation and revision.
SL: Data collection, Performed measurements, Statistical analysis.
LL: Study design, Interpretation of data, Revising the manuscript.
LZ: Study design, Interpretation of data, Critical revision.
QL: Study design, Interpretation of data, Manuscript preparation.

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