International Orthopaedics (2019) 43:1635–1642
https://doi.org/10.1007/s00264-018-4090-9

ORIGINAL PAPER

Femoral anteversion does not predict redislocation in children with hip dysplasia treated by closed reduction

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Received: 28 February 2018 / Accepted: 1 August 2018 / Published online: 14 August 2018

Abstract

Purpose Increased femoral anteversion can be associated with hip instability, redislocation after closed reduction, and subsequent early degenerative arthritis.

Our study compared proximal femoral anteversion of affected and unaffected sides of patients with unilateral developmental dysplasia of the hip (DDH) on two-dimensional computed tomography. The primary aim was to evaluate whether femoral anteversion at the time of treatment affected the outcome of patients with unilateral DDH treated by closed reduction.

Methods A retrospective review of 89 patients (82 females; 53 left; mean age: 26.6 months) with unilateral DDH was performed. Anteversion angle (AA) of the femur and acetabular index (AI) of both affected (AAa; AIa) and unaffected (AAu; AIu) hips were measured on two-dimensional CT scan performed no more than seven days prior to the index surgical procedure.

Results Among the 89 patients, 50 underwent closed reduction (56.2%), 38 underwent open reduction with or without pelvic osteotomy (42.7%), and one patient refused treatment (1.1%). Overall, the mean AAa was 28.1° ± 10.2° (range: 6.3°–54°) and mean AAu was 25.2° ± 9.9° (range: 1.9°–52.5°) ($t = 3.2$, $p = 0.002$). Tönnis type 2 hips did not show any statistically significant difference between AAa and AAu ($p = 0.386$), while Tönnis types 3 and 4 hips had significantly higher AAa than did AAu ($t = 3.7$, $p = 0.001$). There were significant correlations between age and AAa (coefficient = 0.4; $p < 0.001$) and AAu (coefficient = 0.304; $p = 0.004$). Correlation analysis showed that AIa did not improve with age in any Tönnis group (r: − 0.24, $p = 0.823$; F = 0.039, $p = 0.962$).

AAa, AIa, AAD, AID, and Tönnis grade distribution were similar in patients with good (no redislocation) and poor outcomes (redislocation) ($p > 0.05$).

Conclusion In patients with unilateral DDH, anteversion angle (AA) was found to be significantly different between affected and unaffected sides. However, the difference had very limited or no clinical significance, as redislocation/sub-luxation was not influenced by AA values.

Keywords DDH · Unilateral · Femoral anteversion · Acetabular index · Closed reduction

Introduction

Developmental dysplasia of the hip (DDH) is one of the most complex deformities in paediatric orthopaedics, and it has been shown to be associated with early degenerative arthritis if left untreated [1].

Surgical decision-making in patients with DDH is based upon the understanding of the hip anatomy and of the morphological abnormalities of both the acetabulum and the proximal femur [2]. In particular, increased femoral anteversion has been shown to be associated with hip instability, redislocation after closed reduction, and subsequent early degenerative arthritis [3]. In patients with DDH requiring surgical treatment, assessment of femoral anteversion was important in order to achieve satisfactory clinical and radiological outcomes and to minimize complications [4]. However, surgical indications for proximal femur osteotomy in patients with DDH are not universally accepted and remain

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Table 1 Demographic of patients

Number of patients	89	
Male:female	7:82 (7.9%:92.1%)	
Mean age at examination (months)	26.6 (range, 7–112)	
Side of dislocation (left:right)	53:36 (59.6%:40.4%)	
Tönnis grade (II:III:IV)	49:23:17 (55.1%:25.8%:19.1%)	$p < 0.001$
Mean age Tönnis II:III:IV (months)	20.2: 26.5: 45.1	
Acetabular index (mean ± SD)	Affected side: 37.3 ± 5.1 Unaffected side: 25.6 ± 6.6	p: < 0.001
Anteversion angle (mean ± SD)	Affected side: 28.1 ± 10.2 Unaffected side: 25.2 ± 9.8	p: 0.002
Follow-up times (months)	15.7 ± 6.1	

SD standard deviation

controversial [5, 6]. In particular, some authors reported that femoral anteversion was significantly increased on the affected side of DDH patients compared to the contralateral side, and thus, they recommended proximal femoral derotational osteotomy in this patient population [7–9]. On the other hand, more recent studies could not identify any clinically significant difference between affected and unaffected sides of DDH patients, and authors suggested that proximal femoral derotational osteotomy should not be invariably performed [9–12].

Our study compared proximal femoral anteversion of affected and unaffected sides of patients with unilateral DDH on two-dimensional computed tomography and evaluated the correlation between femoral anteversion, Tönnis grade, acetabular index (AI), age, and poor outcome (redislocation or sub-luxation) after closed treatment. Our primary aim was to evaluate whether femoral anteversion at the time of treatment affected outcome of patients with unilateral DDH treated by closed reduction.

Methods

After first securing approval from the Institutional Review Board, a retrospective review of medical records, anteroposterior (AP) pelvis radiographs, and computed tomography (CT) scans of pelvis and femurs, including the knee joint, was performed on 89 patients (August 2015–May 2017) with unilateral DDH older than six months of age.

The inclusion criteria were as follows: unilateral DDH, no previous treatment (conservative or surgery), absence of comorbidity, and complete radiological data.

The exclusion criteria were as follows: bilateral DDH, history of prior treatment (conservative or surgical), presence of genetic (i.e., skeletal dysplasia) or neuro-muscular (i.e., cerebral palsy) disease, and/or incomplete radiological data.

Demographic and clinical data were recorded as follows: gender, side, age at time of radiographic examination, side operated, and length of follow-up (Table 1).

All patients underwent AP pelvis radiographs. Severity of DDH was rated according to the Tönnis classification system [13, 14] and by measuring the acetabular index (AI) on both the affected and unaffected sides [13, 14] (Table 1).

All patients underwent pelvic and bilateral femoral CT scans, including knee joints. All CT scan examinations were performed on a Brilliance CT64 scanner (Philips, MA, USA) under sedation, with the lower extremities kept in neutral position.

CT scan images were used to measure the anteversion angle (AA) in the horizontal plane of both the affected and unaffected sides. AA is the angle between the proximal femoral-neck axis and the distal transcondylar axis [15, 16] (Fig. 1). Affected side AA (AAa) and unaffected side AA (AAu) were

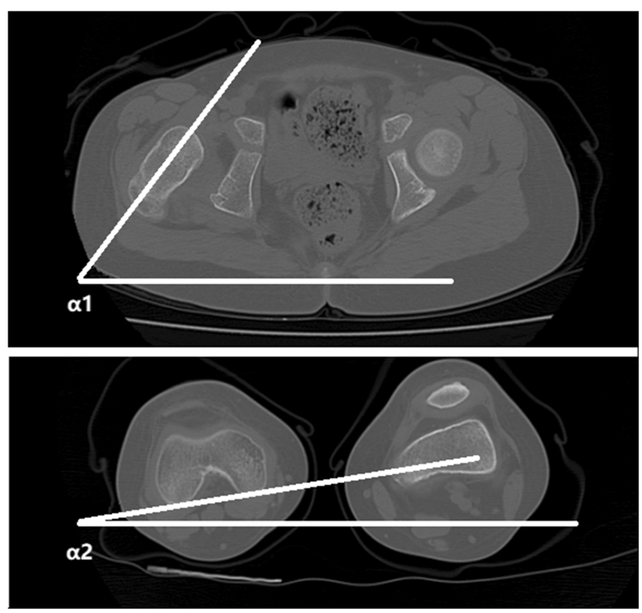

Fig. 1 Two-dimensional CT scan measurement of anteversion angle (AA). Firstly, the femoral-neck angle (**α1**) on the horizontal plane is measured. Secondly, the trans-condylar axis of the distal femur of the horizontal plane (**α2**) is measured. The final AA is given by the difference between **α1** and **α2**

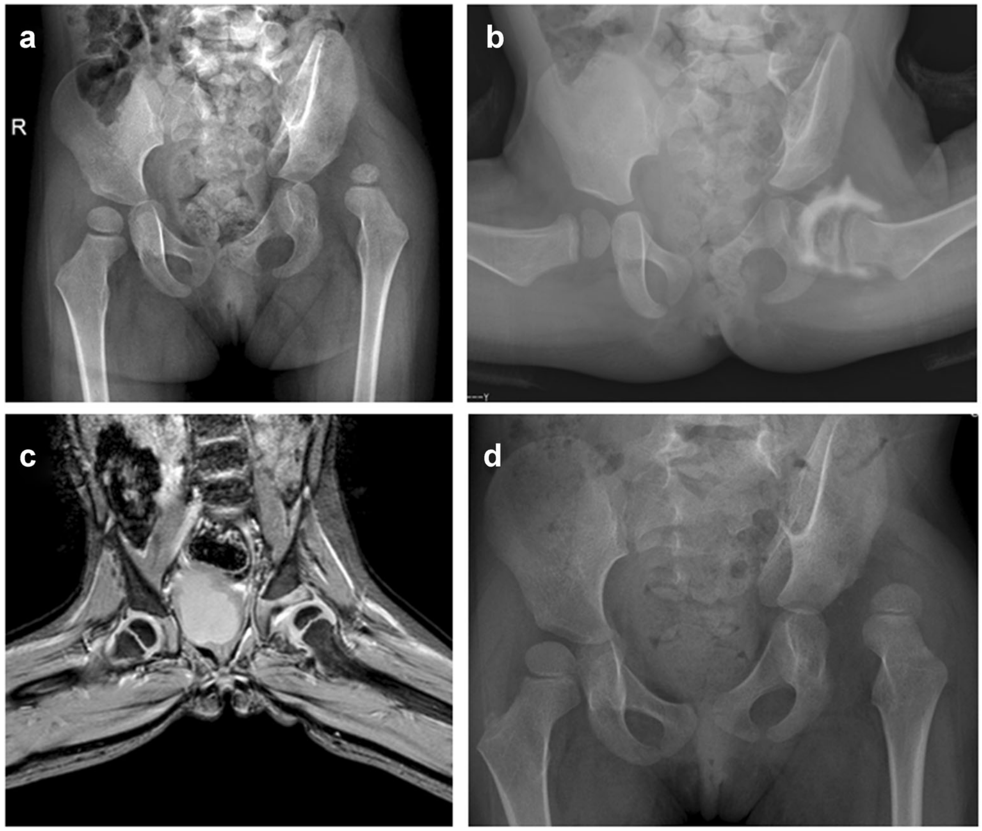

Fig. 2 Preoperative radiograph of a 21-month girl with right hip dislocation (**a**); closed reduction and spica cast immobilization (**b**); post-operative MRI shows good reduction (**c**); redislocation during follow-up (**d**)

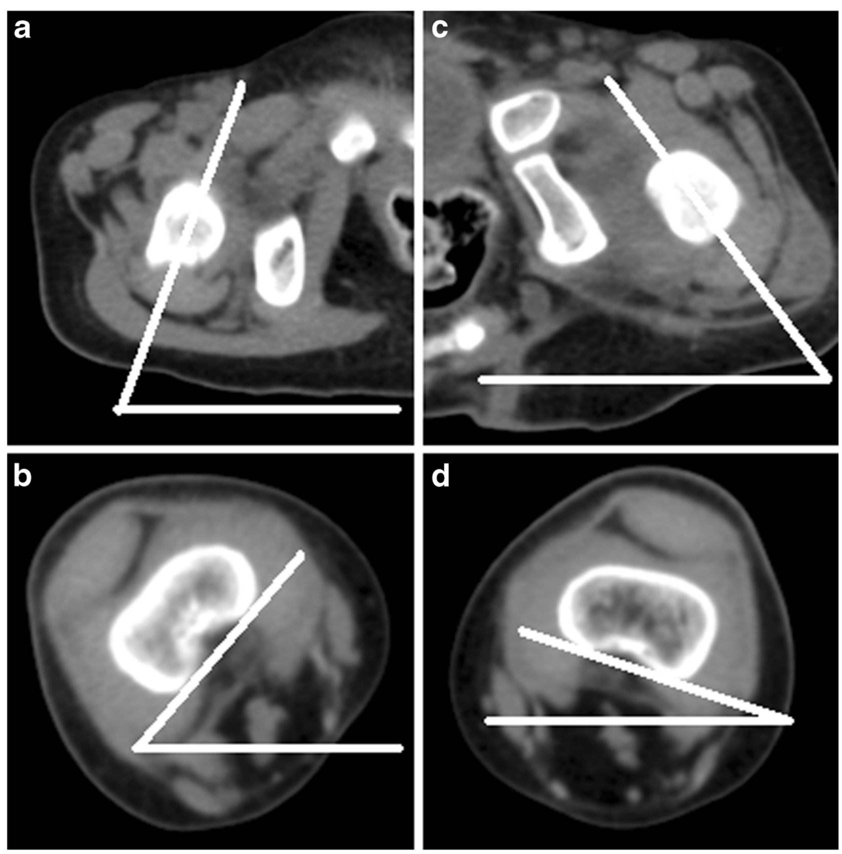

Fig. 3 Pre-operative CT scan of a 21-month girl with poor outcome (redislocation). Anteversion angle (AA) is not significantly different between affected and unaffected sides. Right femoral neck (**a**); right distal femur (**b**); left femoral neck (**c**); left distal femur (**d**)

used to calculate the AA difference (AAD) by subtracting AAu from AAa (AAD = AAa − AAu).

Outcome was judged as *good* when no redislocation or sub-luxation occurred during follow-up (Figs. 2 and 3). Outcome was rated as *poor* when redislocation or sub-luxation was observed during follow-up (Figs. 4 and 5). Redislocation was defined as a complete loss of contact between the joint surface of the femoral epiphysis and the surface acetabulum, while sub-luxation was an incomplete dislocation with partial contact between joint surfaces [14].

Two trained paediatric orthopaedic surgeons assessed all radiographs independently. In case of disagreement, radiographs were shown to a paediatric radiologist to make the definitive diagnosis.

Statistical analysis

Statistical analysis was performed using IBM SPSS version 20 for Windows (IBM Corp, Armonk, NY, USA). The tests were two-sided, with statistical significance set at $p < 0.05$. Patient characteristics were presented as the mean (± standard-deviation). Comparisons of angles between affected and unaffected sides (AA and AI) were performed using the paired *t* test. Comparisons of the angles (AA and AI) between various Tönnis grades were made using ANOVA. Correlation analysis was performed by the Pearson method. Logistic regression analysis was also performed to confirm results.

Results

The study included a total of 89 consecutive patients with Tönnis grades 2 to 4 unilateral hip dislocation (7 males [7.9%] and 82 females [92.1%]) (Table 1). Average age at the time of radiographic assessment was 26.6 months (range: 7–112). The involved side was the left in 53 cases (59.6%) and the right in 36 cases (40.4%). Average follow-up time was 15.7 ± 6.1 months (range: 3–39).

Radiographs and CT scan evaluation

Forty-nine hips were graded as Tönnis type 2 (55.1%), 23 as grade 3 (25.8%), and 17 as grade 4 (19.1%).

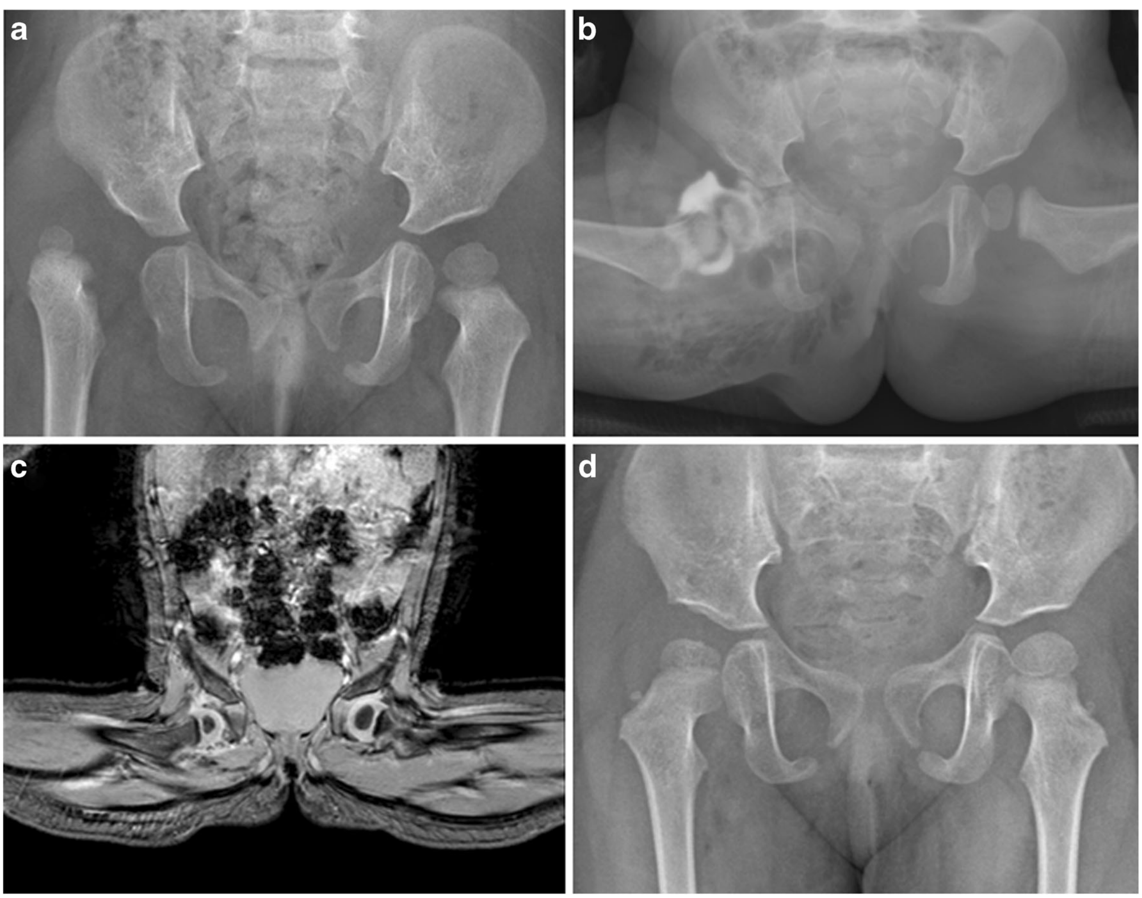

Fig. 4 Pre-operative radiograph of a 19-month girl with right hip dislocation (**a**); intraoperative arthrogram shows concentric reduction (**b**); post-operative MRI confirmed good reduction (**c**); the hip remained located during follow-up (**d**)

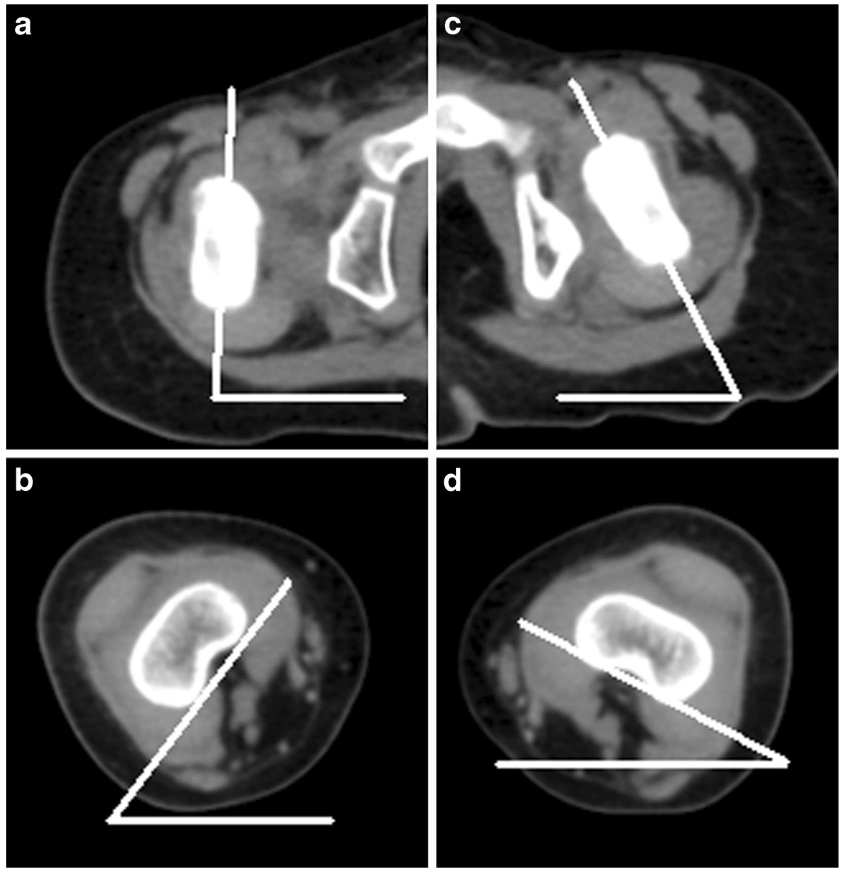

Fig. 5 Pre-operative CT scan of a 19-month girl with good outcome (no redislocation). Anteversion angle (AA) is not significantly different between affected and unaffected sides. Right femoral neck (**a**); right distal femur (**b**); left femoral neck (**c**); left distal femur (**d**)

Overall, the mean AI of the affected side was 37.3° ± 5.1 (range: 24.5–49.9) and the mean AI of the unaffected side was 25.6° ± 6.6 (range: 10.4–42.6) ($t = 15.6$, $p < 0.001$).

Correlation analysis showed that AI of the affected hips did not improve with age in any of the Tönnis groups (r: − 0.24; $p = 0.823$). ANOVA was used to confirm the difference of AIa between Tönnis types 2, 3, and 4 hips (F = 0.039; $p = 0.962$). Table 2 shows the AI of affected and unaffected sides according to Tönnis grade (Table 2).

Table 3 shows AA variations of affected and unaffected sides according to Tönnis grade (Table 3). Overall, the mean AA of the affected side was 28.1° ± 10.2° (range: 6.3°–54°) and the mean AA of the unaffected side was 25.2° ± 9.9° (range: 1.9°–52.5°) ($t = 3.2$; $p = 0.002$). Tönnis type 2 hips did not show any statistically significant difference between AA of affected and unaffected sides ($p = 0.386$) (Figs. 3 and 5). However, Tönnis types 3 and 4 hips showed significantly higher AA on the affected side than on the unaffected side ($t = 3.7$; $p = 0.001$). Correlation analysis showed that there was a significant correlation between age and AA for both the affected (coefficient = 0.4; $p < 0.001$) and the unaffected sides (coefficient = 0.304; $p = 0.004$). According to age groups, we found that patients older than 24 months had significant anteversion angle differences (AAD) between affected and unaffected sides ($t = 3.5$; $p = 0.002$) (Table 4 and Fig. 6). ANOVA analysis confirmed this finding (F = 14.1, $p < 0.001$ in AAa and F = 5.7, $p = 0.005$ in AAu) (Table 4 and Fig. 7).

Table 2 Acetabular index (AI) of hips according to Tönnis grade and affected/unaffected side

Tönnis grade	*N*	AI of affected side	AI of unaffected side	*t*	*p* value
2	49	37.2 ± 5.3	27.1 ± 6.5	10.3	< 0.001
3	23	37.5 ± 4.6	24.4 ± 6.4	8.2	< 0.001
4	17	37.5 ± 5.5	22.5 ± 6.1	9.6	< 0.001
Total	89	37.3 ± 5.1	25.6 ± 6.6	15.6	0.001

Table 3 Anteversion angle (AA) of hips according to Tönnis grade and affected/unaffected side

Tönnis grade	*N*	AA of affected side (degrees)	AA of unaffected side (degrees)	*t*	*p* value
2	49	25.9 ± 10	24.9 ± 10.6	0.9	0.386
3 and 4	40	30.8 ± 9.8	25.5 ± 9	3.7	0.001
Total	89	28.1 ± 10.2	25.2 ± 9.9	3.2	0.002

Table 4 Anteversion angle of affected (AAa) and unaffected hips (AAu) according to age

Age	*N*	AAa	AAu	*p* value
< 11 months Not ambulatory	7	23.6 ± 11.3	19.1 ± 10.0	0.324
12–23 months Onset of walking	56	25.0 ± 8.5	23.7 ± 9.2	0.206
Over 24 months Ambulatory	26	35.9 ± 9.0	30.0 ± 9.4	0.002
F		14.1	5.7	
P value		< 0.001	0.005	

Treatment outcome

Among the 89 patients with unilateral DDH, 50 underwent closed reduction and minimally invasive surgery (percutaneous adductor tenotomy and arthrogram) and spica cast immobilization (56.2%), 38 underwent open reduction with or without pelvic osteotomy (42.7%), and one patient refused any kind of treatment (1.1%).

No cases of redislocation were observed after open reduction. However, 16 patients out of 50 (32%) who underwent closed reduction and minimally invasive surgery had poor outcome. AAa, AIa, AAD, AID, and Tönnis grade were not predictors of poor outcome (Table 5). Logistic regression analysis confirmed that all variables could not predict outcome effectively (Tönnis grade: $p = 0.217$; AIa: $p = 0.961$; AAa: $p = 0.802$; Age: $p = 0.256$).

Discussion

We found that although anteversion angle (AA) was different between affected and unaffected sides in patients with unilateral DDH, the difference had very limited or no clinical significance because redislocation/sub-luxation was not influenced by AA values.

At present, findings of AA in patients with DDH remain controversial [3, 4, 9–12, 17–19]. In the past, the idea was promoted that DDH was frequently associated with increased AA. In particular, Sankar et al. recommended performing femoral derotational osteotomy in patients with anteversion over 50° and to aim for 20° to 30° of femoral anteversion [3]. Similarly, Wenger et al. recommended up to 30° derotation of the femur in order to decrease the risk of posterior hip dislocation [18]. Moreover, Jia et al. recommended that derotation of the femur should be considered in cases of severe AA only, exceeding 60° [9].

However, recent studies conducted with CT and MRI scans did not observe any significant difference in AA between the affected and unaffected hips of walking-age patients with DDH [9–12]. In addition, post-operative MRI is helpful in detecting hips that remain dislocated after CR and spica cast immobilization [12]. Sezgin et al. [4] compared the

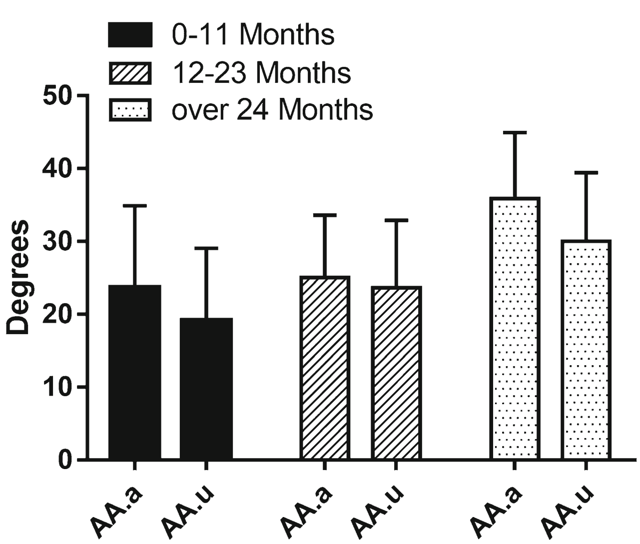

Fig. 6 Femur anteversion of affected and unaffected sides according to age

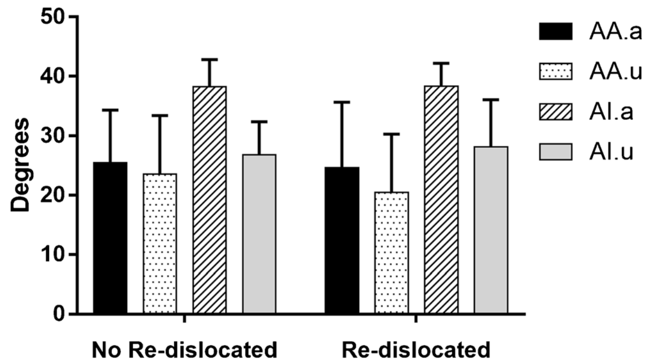

Fig. 7 Acetabular index and femur anteversion of affected and unaffected sides according to outcome (redislocation versus no redislocation)

Table 5 Anteversion angle of affected hips (AAa), acetabular index of affected hips (AIa), anteversion angle difference (AAD), acetabular index difference (AID) and Tönnis grade in patients with good (no redislocation/sub-luxation) and poor outcome (redislocation/sub-luxation) after closed reduction

		Good outcome	Poor outcome	t/χ2	*p* value
AAa (degrees)		25.5 ± 8.9	25.6 ± 11.1	0.30	0.768*
AIa (degrees)		38.3 ± 4.4	38.3 ± 3.9	− 0.04	0.969*
AAD (degrees)		11.5 ± 6.3	10.2 ± 7.4	− 0.84	0.527*
AID (degrees)		1.9 ± 8.7	4.1 ± 8.7	0.64	0.407*
Tönnis grade	2	*N* = 26	*N* = 10		0.330**
	3–4	*N* = 8	*N* = 6		
Total (*N*)		*N* = 34	*N* = 16		

N number of patients

* Student *t* test

** χ^2 test

AA difference between 44 affected and ten unaffected hips of patients with unilateral DDH using two-dimensional CT scan. They found a 2.2° difference on average between affected (32.9° ± 6.4°) and unaffected sides (30.7° ± 6.1°). Our findings were similar, with an average difference of 2.9° found between affected (28.1° ± 6.1°) and unaffected sides (25.2° ± 6.1°). Moreover, due to the larger population size of our study, we were able to evaluate AA according to Tönnis grade and age. Interestingly, we found that, although older patients with higher Tönnis grades had greater AA values, this did not impact redislocation rate. This finding is probably related to the low difference between AAa and AAu of our sample population, 2.9° on average. Moreover, none of our patients had AAa exceeding 60° [9] (Figs. 2, 3, 4 and 5).

In Tönnis type 3 and type 4 hips, the AA of affected side was significantly higher than were Tönnis type 2 hips (30.8° versus 25.9°, on average; p: 0.001). However, no significant difference was found when unaffected sides were compared (24.9° versus 25.6°, on average; p: 0.386) (Table 3). This can potentially be explained by a higher mean age of patients with Tönnis type 3 and type 4 hips (34.4 months) compared to age of patients with Tönnis type 2 hips (20.2 months; $p < 0.001$) (Table 1). Our study revealed that AA significantly increased with age in both affected and unaffected hips. More severely dislocated hips showed a significantly greater increase, although this did not influence redislocation rate. Interestingly, the increase was more significant after the onset of walking in both affected (+ 10.9°, on average; p: < 0.001) and unaffected hips (+ 6.3, on average; p: 0.006) (Table 5). However, although statistically significant, they had little or no clinical impact, because overall the analysis of our data showed that AI, AA, and Tönnis grade could not independently predict redislocation in patients with unilateral DDH treated by closed reduction and spica cast immobilization. In particular, Li et al. reported that AI continues to improve until seven years after closed reduction in hips with satisfactory outcomes, while it ceases to improve sooner in hips with unsatisfactory results [10]. Thus, hips requiring subsequent surgery should be tested to determine when to perform a derotation osteotomy. A test of stability based on intra-operative findings may avoid unnecessary surgical procedures. In this respect, Zadeh et al. suggested that the amount of AA and intra-operative stability of the hip should guide the surgeon regarding whether or not to perform a derotation osteotomy of the femur in patients with DDH [19].

We encountered some limitations in the analysis of our results. First, the accuracy of the two-dimensional CT scan for the quantitative assessment of AA in children with DDH has been questioned [20, 21]. In particular, Li et al. reported that three-dimensional CT scan assessment showed better intra- and inter-observer agreement than did two-dimensional CT scan analysis in patients with DDH [22, 23]. To reduce positional variables, all our patients underwent CT scan examination in a standard position. All CT scans were performed in the same paediatric radiology department, and one senior orthopaedic surgeon performed all measurements in order to reduce inter-observer variability. Second, patients underwent pre-operative CT scan only; post-operative CT scans were not performed in order to limit radiation exposure in these patients. However, all pre-operative CT scans were performed between one and seven days prior to closed reduction and spica cast immobilization. Thus, we can assume that AA remained unchanged between CT scan and index procedure. Third, the overall number of patients was relatively low. However, the present series was the largest to date assessing AA and redislocation rate in patients with unilateral DDH.

Despite these limitations, we showed that increased AA was encountered in older patients with higher dislocation (Tönnis type 3 and type 4 hips). However, despite statistically significant differences in AA between affected and unaffected sides, clinical significance was limited. Not only AA but also AI and Tönnis grade, were not found to predict poor outcome (redislocation) in patients with unilateral DDH. We feel that surgeons should rely more on clinical stability of the hip after reduction than on radiological measurements alone.

Funding information No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Compliance with ethical standards

Conflicts of interest The authors have no conflicts of interest to disclose.

Ethical approval 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.

Informed consent No patients were involved. This is a retrospective study of patient's data, and an IRB approval was obtained.

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