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ORIGINAL PAPER

Similar femoral growth and deformity with one screw versus two smooth pins for slipped capital femoral epiphysis

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Abstract

Purpose To compare longitudinal growth and cam deformity of the proximal femur after treatment for slipped capital femoral epiphysis (SCFE) with one screw versus two smooth pins.

Methods We studied 43 patients (29 males, 14 females; mean age, 12.1 years; range, 9.5–14 years) with idiopathic unilateral SCFE treated with in situ fixation with one cannulated screw (group A, $n = 23$) or two smooth pins (group B, $n = 20$). Anteroposterior and frog-leg radiographs of the pelvis were evaluated for each patient at initial presentation, post-operatively and at physeal closure. Longitudinal growth was evaluated using the femoral neck length (FNL), the caput–collum–diaphyseal (CCD) angle, and the articulo-trochanteric distance (ATD). Cam deformity was assessed using the anterior offset α-angle and the head–neck offset ratio (HNOR). The mean follow-up was 5.1 years (range, 4–7 years).

Results Postoperatively, the mean CCD angle was 138.3°, the mean α-angle was 66.1° and the mean HNOR was − 0.030. At physeal closure, mean CCD angle significantly decreased to 133.6°, mean α-angle significantly reduced to 52.1°, and mean HNOR significantly improved to + 0.039. CCD, FNL, ATD, α-angle, and HNOR were not different between groups.

Conclusions One screw or two smooth pins result in similar longitudinal growth and deformity of the proximal femur after SCFE. The femoral head–neck junction remarkably improves until physeal closure; however, residual cam deformity is not avoided after in situ pinning. The complication rate with smooth pins is higher.

Keywords Slipped capital femoral epiphysis · In situ fixation · Smooth pins · Cannulated screw · Cam deformity · Femoroacetabular impingement

Introduction

Slipped capital femoral epiphysis (SCFE) is an important hip disorder in children and adolescents. The overall incidence ranges from one to ten per 100,000 children/adolescents, with an onset at age 11–13 years in girls and 13–15 in boys [1]. Goals of treatment include restoration of hip function, prevention of further slip, and avoidance of complications, such as proximal femoral deformity, osteonecrosis, and chondrolysis [1].

There are conflicting reports regarding the optimal treatment and implants of choice for SCFE [2–7]. Additionally, continuous growth of the capital femoral physis (CFP) and proximal femur deformity after treatment for SCFE remain a concern [3–8]. Epiphysiodesis via in situ fixation with one screw is considered the safe standard of care, offering reliable stabilization with low complication rates [1, 9, 10]. However, persistent abnormality in the head–neck relationship may result in femoroacetabular impingement (FAI) that has been associated with progressive

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development of early arthritis. Additionally, premature closure of the CFP may result in short femoral neck length (FNL) and leg length discrepancy (LLD) [2]. In this context, fixation with smooth implants, Kirschner wires [7], Steinmann pins [5], hook pins [8], dynamic screws [4], or other [3, 6], has been recommended to prevent the epiphysis from further slip, while permitting longitudinal growth of the active physis, reducing deformity and FAI [4–8].

Therefore, we performed this study to compare longitudinal growth and cam deformity of the proximal femur after in situ fixation of SCFE with one cannulated screw versus two smooth pins. Our key question was if smooth implants yield superior outcome at physeal closure.

Patients and methods

We retrospectively reviewed the files of all patients with SCFE admitted and treated at the authors' institutions from 2000 to 2010. We included only patients with unilateral SCFE, in situ fixation, and a full set of follow-up radiographs; we excluded patients with bilateral SCFE, those who underwent prophylactic fixation, and those with acute SCFE that underwent intentional or reluctant intraoperative reduction. This left us 43 patients (29 boys, 14 girls; mean age, 12.1 years; range, 9.5–14 years) for analysis. The mean age at the time of surgery for the boys was 12.9 years (range, 9.5–14 years) and for the girls was 11.3 years (range, 10–13 years). Based on Loder's classification [11], 36 patients had a stable and seven patients had an unstable SCFE. Based on the lateral epiphyseal shaft angle classification of Southwick [12], 22 patients had a mild (< 30°), 17 patients had a moderate (30°–50°), and four patients had a severe (> 50°) SCFE; overall, the mean lateral epiphyseal shaft angle was 24.1°. Southwick's angle was recorded preoperatively and immediately post-operatively to identify potential slip changes. The mean follow-up was 5.1 years (range, 4–7 years); no patient was lost to follow-up. No patient was specifically recalled for that study; all data were retrieved from the patients' files. All patients or their parents gave written informed consent for their data to be included in this study. This study was approved by the Institutional Review Board/Ethics Committee of the authors' institutions.

Under general anesthesia and fluoroscopy guidance, all patients had in situ fixation of their SCFE; 23 patients were treated with one partially threaded, stainless steel 6.5-mm cannulated screw (Asnis®, Stryker GmbH, Selzach, CH) (group A), and 20 patients were treated with two 3-mm smooth pins (group B). Screws were aimed at the centre of the femoral neck; smooth pins were inserted in a parallel fashion. All procedures were done by the same pediatric orthopedic surgeons (CZ and DP); the method of fixation was chosen according to surgeons' preference (CZ, screws fixation; DP, pins fixation). Post-operatively, patients with stable SCFE were allowed to bear weight as tolerated, while those with unstable SCFE were allowed for partial weight bearing of the affected limb with crutches for four to six weeks, and unrestricted weight-bearing thereafter.

Postoperative routine follow-up clinical and imaging examinations were performed at two weeks, six weeks, and three months, and at six month intervals thereafter until CFP closure. For the purpose of this study, CFP closure was considered an endpoint, as the implants were removed and could not affect potential changes thereafter. CFP closure was considered when at least 50% fusion was evident on AP and frog-leg lateral radiographs of the pelvis, with corresponding loss of lucency at the physeal area [3, 13]; at this point, the implants were removed in all patients. The mean time of slipped CFP closure was 13.9 months (range, 6–36 months). Imaging evaluation at presentation and follow-up included anteroposterior (AP) and frog-leg lateral radiographs of the pelvis. Radiographs were performed by specialized personnel in children radiography. The patients were supine on the radiographic table, with arms placed at the side or across the upper chest. The source to film distance was 100 cm. Care was taken to avoid rotation of the pelvis; the distance from tabletop to each anterior superior iliac spine (ASIS) should be equal, and the upper border of the cassette was positioned 2.5–3.8 cm above the iliac crest. For the AP radiograph of the pelvis with bilateral hips, the feet were placed in approximately 15°–20° of internal rotation to overcome the normal anteversion of the femoral necks and to place their longitudinal axes parallel to the film, and the heels were 20–24 cm apart. For the frog-leg lateral radiographs of the pelvis, the knees were flexed, the soles of the feet put together, and thighs abducted. The radiographic beam was directed vertically to a point slightly above the pubis symphysis. In preoperative, immediate postoperative, and CFP closure radiographs, we evaluated longitudinal growth and cam deformity of the proximal femur. The affected (SCFE) hip was compared to the healthy (contralateral) hip.

Longitudinal growth was evaluated on AP radiographs with the (a) caput–collum–diaphyseal (CCD) angle [14], (b) FNL [7], and (c) articulo-trochanteric distance (ATD) [15]. CCD angle was determined by the intersection of a line parallel to the femoral neck (through the centre of the femoral head) and a line along the axis of the femoral diaphysis (Fig. 1). FNL was determined as the distance between the intertrochanteric line and the femoral head, across the centre of the femoral head (Fig. 2). ATD was measured from the superior margin of the greater trochanter to the superior margin of the femoral head, across the axis of the femoral diaphysis (Fig. 3). To avoid magnification errors between radiographs, FNL and ATD were transformed into FNL ratio (FNLR) and ATD ratio (ATDR), respectively, by dividing the measurements of the slipped hip to the corresponding measurements of the contralateral (healthy) hip. Normal FNLR and ATDR are close to one (1/1). Lower values indicated impaired longitudinal growth of the affected epiphysis (the closer to 1/1, the closer the longitudinal growth to normal).

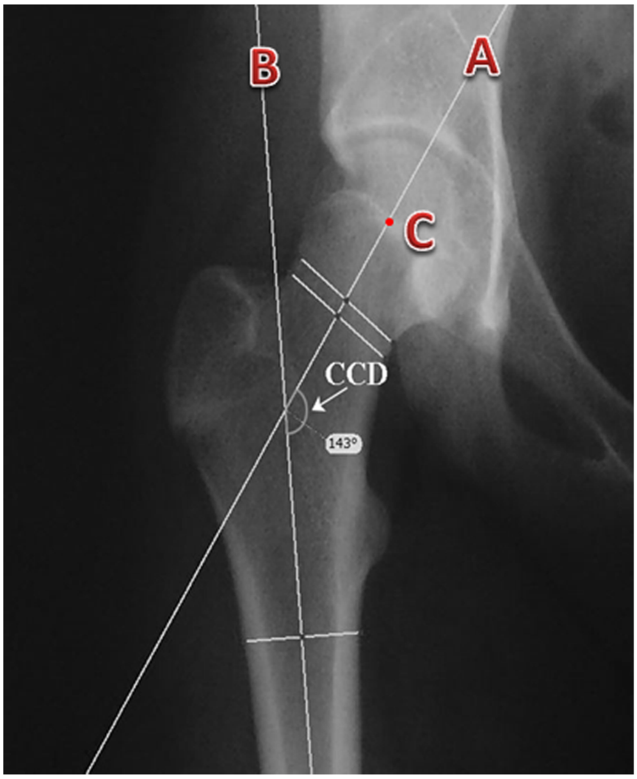

Fig. 1 The CCD angle is measured between the line parallel to the femoral neck (A) through the center of the femoral head (C) and the axis of the femoral diaphysis (B)

Fig. 2 The FNL is the distance between the intertrochanteric line and the femoral head across the centre of the femoral head. FNL was transformed to FNLR (SCFE hip/healthy hip) to avoid radiographic magnification errors

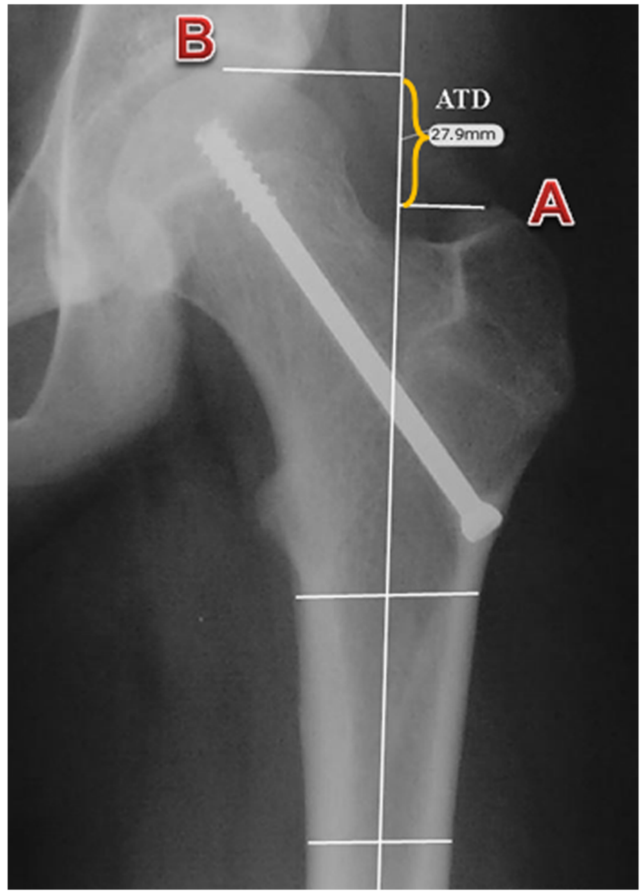

Fig. 3 The ATD is the distance between the summit of the greater trochanter (A) and the summit of the femoral head (B) on the longitudinal axis of the femur. ATD was transformed to ATDR (SCFE hip/healthy hip) to avoid radiographic magnification errors

Cam deformity was evaluated on frog-leg lateral radiographs with the (a) α-angle of Nötzli [16] and (b) anterior head–neck offset ratio (HNOR) [17]. The α-angle was determined by the angle measured between a straight line drawn between the centre of the femoral head and the center of the femoral neck at its narrowest point, and another line drawn from the centre of the femoral head to the point where the head–neck junction intersected the ideal circumference of the femoral head (Fig. 4) [17]. HNOR was calculated by dividing the head–neck offset by the head diameter; the head–neck offset was initially determined drawing a line through the longitudinal axis of the femoral neck, a second line parallel to the first and tangent to the anterior femoral neck, and a third line parallel to the two others and tangent to the anterior outline of the head. The head–neck offset was defined as the distance between the second and third lines. Then, the diameter of the head was measured through its centre and perpendicular to the three aforementioned lines (Fig. 5). An α-angle of > 42° and HNOR < + 0.17 were considered suggestive of cam deformity [18].

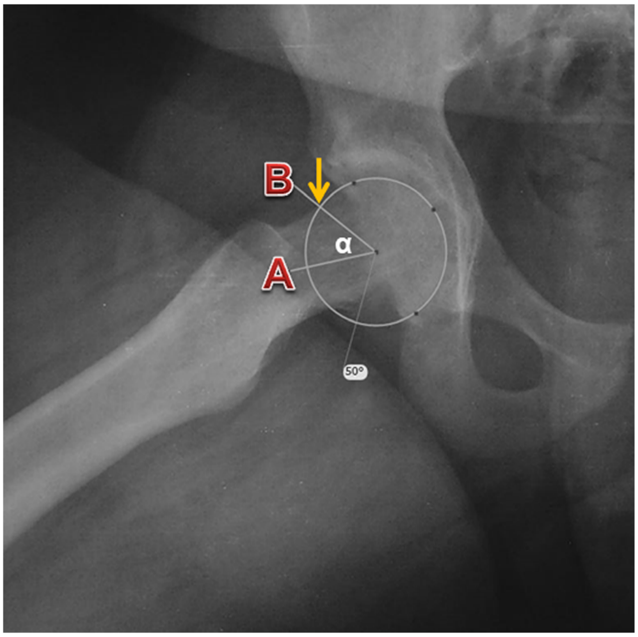

Fig. 4 The α-angle is measured between line A and line B. Line A is the axis of the femoral neck. Line B connects the centre of the femoral head to the point where the anterior cortical surface of the femoral head–neck junction intersects the ideal circumference of the femoral head

Complications such as avascular necrosis (AVN), chondrolysis, degenerative changes, infection, bursitis, and implant loosening or breakage were recorded (Figs. 6 and 7). Collapse of any part of the affected femoral head was considered AVN, while joint space reduction > 50%, as compared to the healthy hip, was considered chondrolysis [10].

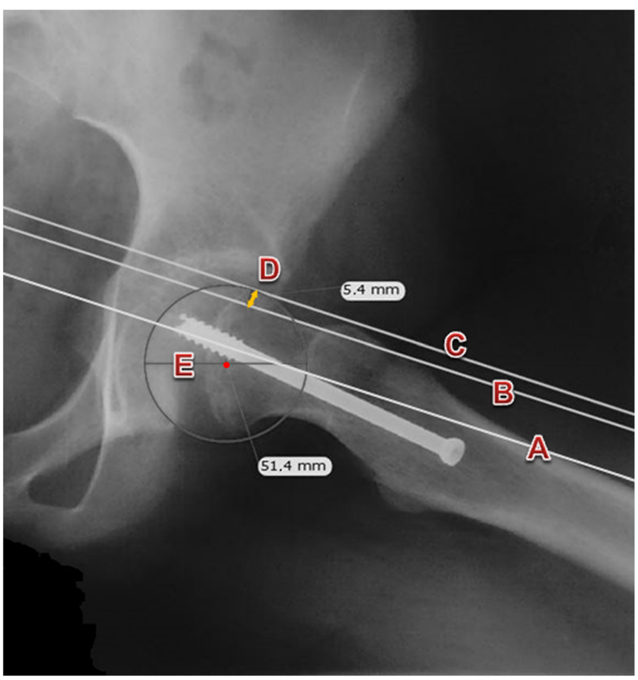

Fig. 5 The HNOR is the perpendicular distance (D) between lines B and C, through the centre of the femoral head, divided by the head diameter (E). Line A is the longitudinal axis of the femoral neck not necessarily through the centre of the head. Line B is parallel to line A, tangent to the anterior part of the neck. Line C is parallel to the others, tangent to the anterior part of the head

All radiographic parameters (Southwick's angle, CCD, FNL, ATD, HNOR, α-angle, and CFP closure) were measured by a consultant orthopaedic surgeon (GNP) and an orthopaedic resident (PDM), and were assessed independently by the same observers (GNP and PDM) using the digital orthopaedic templating software TraumaCad® (Brainlab, Inc., Munich, DE), each one in two periods with 1-month interval. The inter-observer and intra-observer agreement of these parameters was assessed with intraclass correlation coefficient (ICC) and interpreted as slight agreement (< 0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), substantial agreement (0.61–0.80), and almost perfect agreement (> 0.80) [19]. The mean value of each radiographic parameter recorded by the two observers was calculated and was further analyzed. Independent and paired sample *t* tests were used to compare the differences between radiographic parameters. Statistical analysis was performed using IBM SPSS Software, v.22.0. (IBM Corp., NY, USA).

Results

Southwick's angle at presentation was similar between the two study groups ($p = 0.500$), indicating that there was no difference in SCFE severity between them. Southwick's angle immediately post-operative was also similar to the pre-operative value ($p = 0.230$), suggesting that no further slip or reluctant reduction occurred during surgery. The time of CFP closure was similar in the two groups; the mean time of CFP closure was 16.3 months (SD ± 8.4) in group A, and 12.4 months (SD ± 4.9) in group B, without any statistically significant difference ($p > 0.050$) (Table 1).

Longitudinal growth as recorded by the CCD angle, FNL, and ATD was also similar in the two groups. Post-operatively, the mean CCD angle of all patients was 138.3°. At CFP closure, the mean CCD angle significantly decreased to 133.6° ($p < 0.001$), without, however, any statistically significant difference between the two groups ($p = 0.056$). Overall, the mean FNLR and ATDR significantly decreased (deteriorated) from 0.97 to 0.93 ($p < 0.001$) and from 0.83 to 0.69 ($p < 0.001$), respectively, without, however, any statistically significant difference between the two groups (FNLR, $p = 0.460$; ATDR, $p = 0.840$). The femoral neck growth negatively correlated with the age of SCFE onset ($p < 0.010$, $r = 0.69$). Cam deformity was similar at CFP closure in the two groups. Post-operatively, the mean α-angle of all patients was 66.1° and the mean HNOR was − 0.030. Overall, the mean α-angle significantly decreased (improved) to 52.1° ($p < 0.001$), and the mean HNOR significantly increased (improved) to + 0.039 ($p < 0.001$) at CFP closure, without, however, any statistically

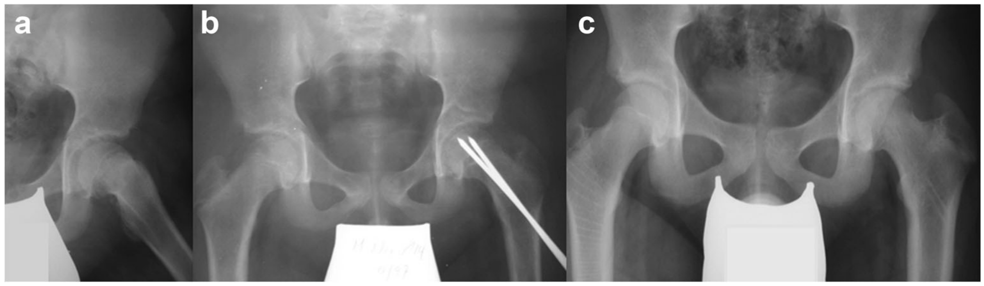

Fig. 6 **a** Frog-leg radiograph of the pelvis of a 14-year-old boy with SCFE of the left hip. **b** AP radiograph immediately post-operatively shows in situ fixation with two smooth pins. **c** AP radiograph 15 months after surgery at CFP closure and implant removal

significant differences between the two groups (α-angle, $p = 0.600$; HNOR, $p = 0.320$) (Table 2).

All examined radiographic parameters showed acceptable (moderate, substantial, or almost perfect) intra-observer and inter-observer agreement (CCD, 0.84 and 0.74; FNL, 0.97 and 0.89; ATD, 0.95 and 0.92; α-angle, 0.91 and 0.88; HNOR, 0.89 and 0.77; CFP closure, 0.94 and 0.86).

No patient experienced any major complications within the study period. In six patients of group A, screw removal was difficult because the screw head was covered with bone. Implant removal was easier in group B; however, seven patients of group B developed trochanteric bursitis due to the protruding pins. In four patients of group B, 1-cm retrograde migration of one of the pins was observed, which did not require a reoperation and did not influence the final outcome.

Discussion

In situ fixation represents the safe gold standard for SCFE; however, there are conflicting reports regarding the optimal implants for fixation [1, 3–7, 9, 10]. One cannulated screw aiming for physeal arrest is a widely accepted implant of choice, with low complication rates [1, 9, 10]. The use of smooth implants has also been advocated, to prevent early closure of the active CFP, allow further longitudinal growth, and reduce residual deformity, especially in younger patients with significant remaining growth potential [3–7]. The present study showed similar outcome of one screw versus two smooth pins with respect to time to CFP closure, longitudinal growth, and residual deformity of the proximal femur after SCFE. Complications included difficulties in screw removal in group A, and bursitis of protruding pins and pin migration in group B.

We acknowledge several limitations in this study. First, as a retrospective evaluation of radiographs, it lacks correlation with clinical data. Second, the number of patients is relatively small, limiting the power of our results. Third, the patients were not very young, limiting the potential of CFP for longitudinal growth. However, we do not believe that this is a major weakness, as our patients' mean age was similar with that of related studies [3–6]. Fourth, this study focused on a small time period, from index surgical procedure to CFP closure and implants removal, as this was considered the endpoint for the impact of the implants. We acknowledge this limitation and did not evaluate for remodeling of the proximal femur in this series of patients; follow-up must be sufficiently longer to allow for important conclusions to be drawn with respect to remodeling and residual deformity of the proximal femur. Fifth, we did not include the Loder's classification in our analysis between the study groups. We acknowledge that a stable/unstable SCFE may have an impact on anatomy, femoral growth, deformity, and remodeling process of the proximal femur after SCFE and treatment. However, the number of patients with an unstable SCFE in this study was very small, limiting a valid comparison between the two groups of patients. Last, the assessment of the exact CFP fusion time may also consist a limitation. The retrospective design of the study and evaluation of radiographs of predetermined follow-up visits (6-month intervals) could compromise this result. In this setting, the radiographic assessment of the exact fusion time may be subjective and as such, questionable. We tried to

Fig. 7 **a** Frog-leg radiograph of the pelvis of a 12-year-old girl with SCFE of the left hip. **b** AP radiograph immediately post-operatively shows in situ fixation with one screw. **c** AP radiograph 19 months post-operatively at CFP closure and implant removal

Table 1 Time from diagnosis and treatment to CFP closure of the patients included in this series. The time to CFP closure was not statistically significantly different between the study groups

Variables	Patients (*n*)	Mean time to CFP closure (months)	SD	*p* value
All SCFE patients	43	13.9	6.6	–
Group A (one screw)	23	16.3	8.4	*0.128*
Group B (two smooth pins)	20	12.4	4.9	

CFP, capital femoral physis

minimize this bias with defining fusion as at least 50% loss of lucency at the physeal area; using this criterion, we found acceptable agreement between the two observers.

Longitudinal growth of the SCFE hip was not found to be enhanced by the type of implants. This can also be deducted by the similar time to CFP closure in both groups. Our findings are in contrast with the findings of other authors that report favorable outcomes after smooth pins fixation that prevents premature CFP closure and allows further growth to the proximal femur [3]. In that study, radiographic parameters were compared between the SCFE and healthy hips preoperatively and at CFP closure; only femoral width and ATD showed significant differences. The authors concluded that after SCFE fixation, the affected physis grew in a way similar to the unaffected side [3]. This may be attributed, partially, to the younger age of their patients (11.5 years), as a higher growth potential is expected in younger ages. The negative correlation between the mean age of presentation and femoral growth that we observed is in accordance with this speculation. Therefore, the fact that no differences were noted between our two study groups may suggest that longitudinal growth continues regardless the method of fixation in younger patients due to their more active physis.

FNL, as recorded with the FNLR, was similar in the two groups. This can also be explained by the similar time of CFP closure. This finding is in contrast with other reports that support better FNL after smooth pinning for SCFE [3–7]. In a study using Steinmann pins, with similar age range with the present series, the authors reported a 9% FNL increase until skeletal maturity. They concluded that the use of Steinmann pins does not cause longitudinal growth arrest [5]. Other authors using a growth-preventing cannulated screw with proximal threading reported a 5-mm FNL growth in the SCFE hip and an even longer in the healthy hip [6]. Further growth has been also reported after screw fixation of SCFE, possibly because of improved histopathology of the CFP after fixation [20]. This is in accordance with the results of the present study that longitudinal growth may continue regardless the method of fixation. Another study compared patients with SCFE treated with three Kirschner wires or a single cannulated screw [21]. The authors observed an adequate residual growth in 58% of the affected hips without a significant difference between Kirschner wire and screw fixation. They also did not observe any increase of deformity during the follow-up period after screw fixation as compared to pinning, and concluded that the assumption that screw fixation leads to permanent

Table 2 Radiographic parameters of longitudinal growth (CCD, FNLR, and ATDR) and CAM deformity (α-angle and HNOR) of the patients included in this series. A statistically significant difference was not observed for any radiographic parameter between the study groups

Radiographic parameters	Patients (*n*)	Mean value	SD	*p* value
CCD				
CCD slipped hip change – group A	23	6.7°	5.8°	*0.056*
CCD slipped hip change – group B	20	3.4°	3.3°	
FNLR				
FNLR deterioration – group A	23	0.04	0.05	*0.460*
FNLR deterioration – group B	20	0.03	0.04	
ATDR				
ATDR deterioration – group A	23	0.15	0.17	*0.840*
ATDR deterioration – group B	20	0.13	0.17	
α-Angle				
α-Angle slipped hip improvement – group A	23	11.2°	9.7°	*0.600*
α-Angle slipped hip improvement – group B	20	13.4°	11.2°	
HNOR				
HNOR slipped hip improvement – group A	23	0.055	0.068	*0.320*
HNOR slipped hip improvement – group B	20	0.070	0.058	

CCD, caput–collum–diaphyseal angle; *CFP*, capital femoral physis; *FNLR*, femoral neck length ratio (slipped/healthy); *ATDR*, articulo-trochanteric distance ratio (slipped/healthy); *HNOR*, head–neck offset ratio physeal impairment cannot be confirmed [21]. In the present study, the mean CCD angle decreased after treatment in both study groups. This may be explained by the normal CCD change occurring with age. However, a steeper decrease of this angle was observed to the slipped side, giving a relatively varus morphology. In situ fixation of SCFE and the remodeling process that follows may explain this change. However, conflicting reports have been reported. Some authors reported a similar difference in CCD angle at skeletal maturity using multiple K-wire fixations [7], while others reported that CCD angle after smooth fixation of SCFE was similar to the healthy hip [6]. ATD represents another measure of proximal femoral geometry. In the present study, we transformed ATD to a ratio. The values of ATDR decreased after fixation in both groups, without any significant difference. This decrease indicates reduction of ATD to the affected side and is suggestive for LLD. Such reduction is frequent in premature closure or other growth disturbances of the CFP. Conflicting reports have also been reported for ATD. Some studies reported significant differences in ATD between the SCFE and healthy hip using a smooth screw [3] or smooth pins [5], while other studies did not report ATD differences using a smooth screw [4, 6]. In a recent study, the authors installed tantalum markers to the femoral neck of patients with SCFE during fixation with a Hansson pin to evaluate the change of position of the epiphysis in relation to the metaphysis immediately postoperatively, after three, six and 12 months [8]. Interestingly, only in half patients, the epiphysis moved according to the expected caudal and medial pattern, suggesting that further growth may be irregular even after smooth pinning due to physeal impairment [8]. Variability of growth of the SCFE hip may be the net effect of many factors with varying degrees of influence, such as the degree of SCFE, stability of fixation, extent of CFP damage, and remaining growth potential [8]. Additionally, the degree of alteration of the enchondral ossification by the disease that would allow substantial growth and remodeling in these patients is unknown [3]. In this regard, we believe that stable fixation of SCFE permits growth of the proximal femur to resume depending on the growth potential of the affected physis and not the fixation type used.

Residual cam deformity was recorded at CFP closure; the mean head–neck offset remained abnormal, even though the mean Southwick's angle represented a mild slip. Based on our measurements, femoral growth and deformity was not influenced by the type of implants; further remodeling may be expected after CFP closure and implant removal, regardless the implant used. Yet, residual deformity should not be overlooked. Continuous impingements may cause groin pain with flexion and eventually labral tear and cartilage degeneration. After in situ fixation, patients usually have a decreased head–neck offset and may experience FAI, even after low-grade SCFE, and hip arthritis in early adulthood [22–24]. In these patients, even with only a few clinical signs of FAI, radiological findings may support the use of osteoplasty to delay or avoid FAI [24].

SCFE fixation with multiple pins is considered susceptible to complications and is generally not recommended [1, 9]. In a study comparing complications between one, two, and three pins fixation in 114 SCFE patients, the authors observed an increasing number of pin-related complications with the increasing number of pins (4.6%, 19.6%, and 36.0%, respectively) [9]. To avoid such complications, some authors that advocate smooth CFP fixation designed special screws with proximal or distal threading [3, 6]. Other authors reported that initially they used three pins and later reduced the number of pins to two, without observing any case of slip progression in any of their patients [5]. This suggests that mechanical stability is not compromised with two smooth pins. In this setting, and considering the increasing complication rate with the increasing number of pins, we used only two smooth pins in this series (group B). In the present series, we observed difficulty in screw removal in group A, and bursitis by protruding pins and retrograde pin migration in group B. Even though this did not influence the outcome, retrograde migration of the smooth pins may compromise the stability of fixation and result in a further slip. Eventually, this can be avoided by using smooth pins with partial distal threading, for better purchase to the femoral head [5]. Finally, smooth pins are easily removed with simple sedation or local anesthesia, while screw removal usually requires open surgery and bone formation may make removal difficult. Aiming for easier removal, the pins were not bent and advanced to bone at SCFE fixation procedure, however, at the cost of more common incidence of bursitis in this group B.

In conclusion, one screw or two smooth pins allow similar longitudinal growth and deformity of the proximal femur after SCFE. Femoral head–neck junction remarkably improves until CFP closure; however, residual cam deformity is not avoided after in situ pinning, even in low-grade SCFE. The complication rate with smooth pins is higher.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest. No benefits have been or will be received from a commercial party related directed or indirectly to the subject matter of this article.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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