Remodelling of femoral head-neck junction in slipped capital femoral epiphysis : a multicentre study

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Remodeling of femoral head-neck junction in SCFE - a multicenter study-

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INTRODUCTION

Slipped capital femoral epiphysis (SCFE) is one of common hip disorders in adolescents. The capital femoral epiphysis displaces postero-inferiorly with respect to the femoral metaphysis, resulting in limited flexion and internal rotation due to anterior impingement between the acetabulum and the femoral metaphysis. The most accepted treatment for a mild to moderate slip is pinning with one or two screws under fluoroscopic imaging with no attempts at reduction of the slip, so-called in situ pinning. Successful clinical results have been reported with in situ pinning [1, 2]. Reports show that most hips had remodeling of the deformed femoral head-neck junction and returned to normal range of hip motion. However, some patients failed to have such remodeling and showed premature osteoarthritis of the hip.

Jones et al. [3] classified SCFE remodeling into three types based on the location of the anterior femoral neck relative to the femoral head. Type A has a femoral head anterior to the femoral neck. In type B, the anterior margin of the femoral head and femoral neck are at the same level. In type C, the femoral head is posterior to the femoral neck and there is a prominence in the mid region of the neck. They defined type A and type B as being completely remodeled and type C as failure of remodeling. This classification system has been widely used in the assessment of remodeling in SCFE.

There has been growing interest in the concept of femoroacetabular impingement (FAI) as an etiological factor for the development of osteoarthritis of the hip [4-7]. Continuous impingements are thought to cause groin pain with flexion and eventually lead to labral and cartilage degeneration. The hips with SCFE, especially after in situ pinning, usually have a decreased head-neck offset (cam deformity) and are thus susceptible to FAI. In fact, 25% of hips in Jones type A exhibited Drehmann sign, which has been used as evaluating the existence of FAI clinically. [8] Therefore, there is a need for re-evaluation of remodeling in SCFE from the view of FAI. We conducted this study to examine the remodeling of femoral head-neck junction and the frequency of cam deformity in patients with SCFE after skeletal maturity.

METHODS

Patients: This multicenter retrospective study was approved by our institutional review board. We analyzed patients with SCFE treated by in situ pinning in the Kyushu University Hospital, Osaka Medical Center, and Fukuoka Children's Hospital. Between 1987 and 2010, 103 hips in 89 patients were treated for SCFE with in situ pinning. We excluded 34 hips with Loder's unstable slips [9], an additional femoral osteotomy, a follow-up period less than 24 months and an incomplete set of radiographs. A total of 69 hips in 56 patients (41 males and 15 females) were included in this study. The mean age at pinning was 11 years and 8 months. All patients were followed at least until skeletal maturity. The mean follow-up after pinning in situ was 5.28 years (ranged 24 months to 368 months). Bilateral hip joint involvement was present in 13 patients. Forty-two hips in an age-matched 42 cases were used as normal controls. These cases were diagnosed as transient arthritis of the hip and the contralateral hips were used. The medical charts and radiographs were reviewed to determine age at presentation, sex, side, weight, body mass index (BMI), methods of fixation, postoperative complications, and outpatient follow-ups.

Radiographic measurements: The radiographic measurements were made digitally using 2D template software (JMM Inc. Osaka, Japan). Slip severity was measured on preoperative lateral radiographs (Lauenstein view) with the posterior sloping angle (PSA) of the physis described by Barrios et al. [10]. The PSA is the angle between the line along the plane of the physis and the line perpendicular to the femoral neck axis. For the assessment of cam deformity, two measurements were performed: the anterior offset angle (α angle) and the head-neck offset ratio (HNOR). Both measurements were performed immediately after pinning in postoperative radiographs and on the most recent review radiograph. α angle was measured on lateral radiographs following the method of Notzli et al. [11] (Fig. 1). In brief, a line was drawn connecting the center of femoral head and the center of femoral neck. A second line is drawn from the center of femoral head to a point on the anterolateral head-neck junction where the radius of femoral head begins to increase beyond the radius found more centrally in the acetabulum where the head is more spherical (i.e., at a prominence). The intersection of these two lines forms α angle. α angle greater than 50° is suggestive of cam deformity [12]. The Head-Neck Offset Ratio, described by Eijer H et al. [13] is also a measure of cam deformity (Fig. 2). The profiles of the anterior head and neck were quantified by measurements of the head-neck ratio. In brief, three parallel lines are drawn, with line 1 drawn through the center of the long axis of the femoral neck, line 2 drawn through the anterior most aspect of the femoral neck, and line 3 drawn through the anterior most aspect of the femoral head. The head-neck offset ratio is calculated by measuring the distance between lines 2 and 3 and dividing by the diameter of femoral head. In the original description by Eijer et al. [13], the mean HNOR was 0.21 with a standard deviation of 0.03 (0.14–0.25), suggesting a lower limit of the reference interval of 0.145. We also measured the Wiberg's CE angle, Sharp angle, and the presence of the cross over sign on the radiographs at the latest follow-up. Hips were classified into three groups based on the Jones classification [5]. All measurements were performed independently by two observers (M.A and Y.K) in a blinded manner during two reviewing sessions held one month apart.

Statistical analysis: The Chi-square test and Wilcoxon rank-sum test were used to compare clinical and radiographic parameters between the two groups. The Dunnett test was used to compare to the control group. The univariate Cox model was applied to each possible risk factor to separately screen for significant factors affecting cam deformity formation. Differences were defined as significant when the *p*-value was < 0.05. A multivariate binary logistic regression analysis was used to determine the predictor variable for a cam deformity. The parameters included in the initial backward stepwise regression were PSA, age at pinning, BMI, CE angle, sharp angle and the cross over sign. The significance to include a variable in the model was $p = 0.20$, and the significance to remove a variable from the model was $p = 0.05$. The cutoff point of the predictor variables was obtained by calculating the receiver-operating characteristic (ROC) curve. The Area Under the ROC Curve (AUC) was calculated using the extended trapezoidal rule assuming relevant AUC ≥ 0.650.

Intraobserver and interobserver reliabilities were evaluated using kappa statistics. Confidence intervals (CIs) of 95% were calculated for the kappa values. Kappa values of 0.4–0.6 indicate moderate agreement, 0.6–0.8 means good agreement, and above 0.8 means excellent agreement.

Results

The average α angle and HNOR at pinning were 76.2 ± 21.1° and 0.086 ± 0.109, respectively. These measurements significantly improved to 51.3 ± 17.2° and 0.135 ± 0.069 at the latest follow-up, respectively (p=0.0003 and p=0.0075, respectively). However, α angle remained significantly larger compared to controls (41.8 ± 4.47°, p=0.0475). (Fig.3) At pinning, 55 hips (86.2%) had α angle greater than 50°. 25 hips (36.2%) still had α angle greater than 50° at the latest follow-up. A similar tendency was observed in terms of HNOR. 46 hips and 32 hips had HNOR less than 0.145 at pinning and at the latest follow-up, respectively. Totally, 43 hips (62.3%) and 20 hips (29.4%) were within the criteria of cam deformity (α angle greater than 50° and HNOR less than 0.145) at pinning and at the latest follow-up, respectively (Table 1).

Among 69 hips, 60 hips were classified as Jones type A, 8 hips as type B, and 1 hip as type C. The number of the hips with α angle more than 50° was 18 hips (30%) in type A, 6 hips (75%) in type B, and 1 hip (100%) in type C. The number of hips with HNOR less than 0.145 was 24 hips (40%) in type A, 7 hips (87.5%) in type B, and 1 hip (100%) in type C, indicating a large number of hips in type A and B classifications still showing cam deformity (Table 1).

We compared the parameters between the hips with and without cam deformity in the SCFE group. (Table 2) The age at pinning was significantly older in hips with cam deformity compared to hips without cam deformity (12.6 ± 1.37 years old vs. 11.4 ± 1.78 years old; $p = 0.0225$). The hips with cam deformity had a significantly larger preoperative PSA versus the hips without cam deformity. (42.2 ± 18.05° vs 28.3 ± 13.6°; $p = 0.0035$)

The parameters included in the initial backward stepwise regression were age at pinning, sex, BMI, PSA, CE angle, sharp angle, and the presence of a cross over sign. Logistic regression analysis using stepwise attribute selection methods indicated that PSA, age at pinning and BMI were predictors for cam deformity. A multivariate analysis also showed that both age at pinning (p = 0.0341) and the preoperative PSA (p = 0.0004) were significant and independent risk factors (Table 3). An older age at operation and greater PSA resulted in higher prevalence of cam deformities. The cut-off value of age at pinning was 11 years and a month old. The AUC was 0.70653, indicating good accuracy. The cut-off value of the slip angle was 21.0 degrees. The AUC was 0.84272, indicating excellent accuracy (Fig. 4).

Intraobserver reliabilities of the measurements, evaluated with the use of the intraclass correlation coefficient, were excellent (range, 0.8045–0.9512). Interobserver reliabilities of the measurements were good (range, 0.6337–0.9391).

Discussion

The remodeling of femoral head neck junction was re-evaluated in terms of the development of cam deformity in this multicenter study. We showed that α angle and HNOR were improved from 76.2° and 0.086 to 51.3° and 0.135 at the latest follow-up, respectively. However, 29.4% of hips still met the criteria of cam deformity at skeletal maturity. We also determined the risk factors for cam deformity formation to be the preoperative PSA and age at pinning. Risks for cam deformity formation include a SCFE diagnosed at age 11.1 years and older and a SCFE slipped 21.0° or more.

The current standard of treatment for a mild to moderate SCFE is in situ pinning with stabilization of the slip and premature physeal closure being the primary goals. Pinning without correction was based on the expectation for bone remodeling. Jones et al. reported that clinically significant remodeling occurred in 90% of patients with mild slips and 50% with moderate slips. Only 11 % of the hips were classified as poor remodeling (type C). Dawes et al. reviewed 59 SCFEs at mean period of 17.7 months. They found that the femoral head-neck relationship, measured by α angle and the distance from Klein's line, approaches normal after in situ pinning of mild to moderate SCFE [14]. In accordance with these studies, our study also showed that 65.8% and 53.7% of hips showed an improved α angle and HNOR within the normal range. Other studies also showed good bone remodeling after mild and moderate slips. [15-16] In relation to the longer follow-up, however, Bellemans et al. showed 10% of the hips showed poor function due to residual deformity at anterior femoral head neck junction in a study of averaging 11.4 years follow-up. [17] Westhoff et al. reported patient's ROM of the hip showed smaller on the slip side and the patients showed totally less positive mechanical work even after growth arrest. [18]

The concept of FAI helps to explain the development of premature osteoarthritis in SCFE, as hips with decreased head-neck offset (cam deformity) are susceptible to continuous impingement. FAI has been described as a cause of pain in the hip in young adult. In a study on patients undergoing hip resurfacing arthroplasty, Beaule et al. found that over 50% of patients with end-stage OA had an insufficient head-neck offset that was consistent with cam-type FAI. [19] Murray suggested that OA could develop secondary to a posterior head tilt due to mild slipped epiphysis. [20] Although our result showed an improvement of head-neck offset by remodeling, 29.4% of SCFE still remained within the criteria of cam deformity. Even in hips within the criteria of Jones Type A and Type B, which was considered to be good remodeling, 22.0% and 85.7% of the hips appeared to have a cam deformity.

To our knowledge, this is the first study to investigate the risk factors for cam deformity after SCFE. The age at pinning and the severity of the slip significantly influenced the rate of cam deformity formation. With the ROC analysis, we found that cam deformities tend to appear in children older than 11.1 years old, and in hips slipped 21.0° or over. Zilkens et al. reported joint degeneration was correlated with clinical scores and not with offset-pathology. [21] In those cases, we recommend close follow-up for a prolonged postoperative period. Our results offer insight into decision making for in situ pinning or in the adaptation of corrective osteotomies in cases of poor remodeling. Additionally, Kandzierski et al. reported that a growth plate finally reaches a shape of a convex meniscus and minor ruggedness of its surface gradually disappears at the age of 11-13. [22] These changes of growth plate might indicate poor ability of remodeling at the age of 11 years and older.

This study had several limitations. As a retrospective evaluation of the database and images, this study lacks a correlation with images and clinical data. A prolonged follow-up period was needed to elucidate the effects of remodeling on the clinical outcomes. Additionally, the normal range of α angle is still controversial. α angle was originally described based on MRI data [11], and is increasingly applied to many imaging modalities. Pollard et al. [12] showed that most patients with cam impingement have α angle in excess of 63°, whereas other studies took 50° as the borderline. This study defined 50° as the upper limit of α angle following Clohisy et al. [11, 19, 23]. Thirdly, some hips were both within the criteria of cam deformity using α angle and without the criteria using HNOR. α angle may be falsely elevated by secondary bony deposition, as a reactive response to FAI [13], or by osteophyte formation as a part of OA. HNOR may be less sensitive to these secondary changes. Considering these factors, we would recommend that α angle and HNOR be used in conjunction.

In summary, we examined the remodeling of the femoral head neck junction. Although the femoral head neck junction was improved by bone remodeling, 29.4% of hips had residual cam deformity. Children over 11.1 years of age at the onset and/or the presence of severe slips over 21.0° predisposed to cam deformity. Even if patients had no hip complaints, the longer follow-up was necessary for these patients.

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Figure captions

Fig. 1 The lateral radiograph of a hip illustrating the method of Notzli et al. [11] for assessing α angle. A line was drawn connecting the center of femoral head and the center of femoral neck. A second line is drawn from the center of femoral head to a point on the anterolateral head-neck junction. The intersection of these two lines forms α angle

Fig. 2 The lateral radiograph of a hip showing the method of Eijer et al. [13] for assessing the head neck offset ratio. A line was drawn parallel to the long axis of the femoral neck through the anterior most aspect of the femoral neck. A second line was drawn through the anterior most aspect of the femoral head. The head-neck offset ratio is calculated by measuring the distance between two lines dividing by the diameter of femoral head.

Fig. 3 Individual values and box plots of α angle (a) and the head neck offset ratio (b). *Significant difference.

Fig. 4 Receiver operating characteristic (ROC) curve for the PSA threshold of 21.0° (a) and for the age at the time of onset threshold of 11.1 years old (b).

Table 1. Radiological parameters as the mean value (SD)

Parameters	Preoperative	Postoperative	Latest follow-up	Control
Radiological parameters				
PSA (degrees)	23.2 (17.1)			
α angle (degrees)		76.2 (21.1)	51.3 (17.3)	41.8 (4.47)
HNOR		0.086 (0.109)	0.135 (0.069)	0.190 (0.029)
CE angle (degrees)			28.1 (6.67)	23.7 (7.62)
Sharp angle (degrees)			41.5 (3.53)	48.5 (3.57)
Jones classification				
Type A (n, %)		37 hips 53.6%	60 hips 86.9%	42 hips 100%
Type B (n, %)		19 hips 27.5%	8 hips 11.7%	0 hip 0%
Type C (n, %)		13 hips 18.8%	1 hips 1.44%	0 hip 0%
The prevalence of cam deformity in SCFE				
α angle > 50° (n, %)		55 hips 86.2%	25 hips 36.2%	2 hips 4.7%
HNOR<0.145 (n, %)		46 hips 71.9%	32 hips 46.4%	3 hips 7.1%
Total (α angle>60° and HNOR<0.145) (n, %)		43 hips 62.3%	20 hips 29.4%	1 hip 2.4%
The prevalence of cam deformity in each Jones class at the latest follow-up				
		α angle>50°	HNOR<0.145	Total
Type A (n, %)		18 hips 30.0%	24 hips 40.0%	13 hips 22.0%
Type B (n, %)		6 hips 75.0%	7 hips 87.5%	6 hips 85.7%
Type C (n, %)		1 hips 100.0%	1 hips 100.0%	1 hips 100.0%

PSA=Posterior Slip Angle. HNOR=Head Neck Offset Ratio. 'Total' included both the alpha angle>50° and HNOR<0.145.

Table 2. Comparison between the presence and absence of cam deformity

	Cam deformity (+)	Cam deformity (-)	λ^2	*p*-value
Age at pinning (years old)	12.6 (1.37)	11.4 (1.78)	5.2083	0.0225*
Gender (M:F)	17:4	35:13	0.508	0.4760
BMI (g/m2)	24.9 (3.33)	25.1 (4.41)	0.1137	0.7360
Body Weight (kg)	31.9 (10.3)	59.0 (14.8)	1.0292	0.3103
PSA (degrees)	42.2 (18.05)	28.3 (13.6)	8.55	0.0035*
CE angle (degrees)	26.4 (6.87)	28.7 (6.50)	1.4711	0.2252
Cross-over sign (n, %)	13 hips 61.9%	26 hips 54.2%	0.356	0.5508

*Statistical significance. Continuous values were presented as means (SD).

Table 3. Predictors For Cam Deformity Using Mulch Regression Analysis

Predictor	Odds Ratio	λ^2	95% CI	*p*-value
PSA	1.08	12.6	0.85889; 0.968275	0.0004*
Age at pinning	1.67	4.49	0.326194; 0.966438	0.0341*
BMI	1.15	2.19	0.695138; 1.044378	0.1384

Multiple logistic regression model. $p = 0.0005$*. $r^2 = 17.57171$. *Statistical significance.

Fig.1

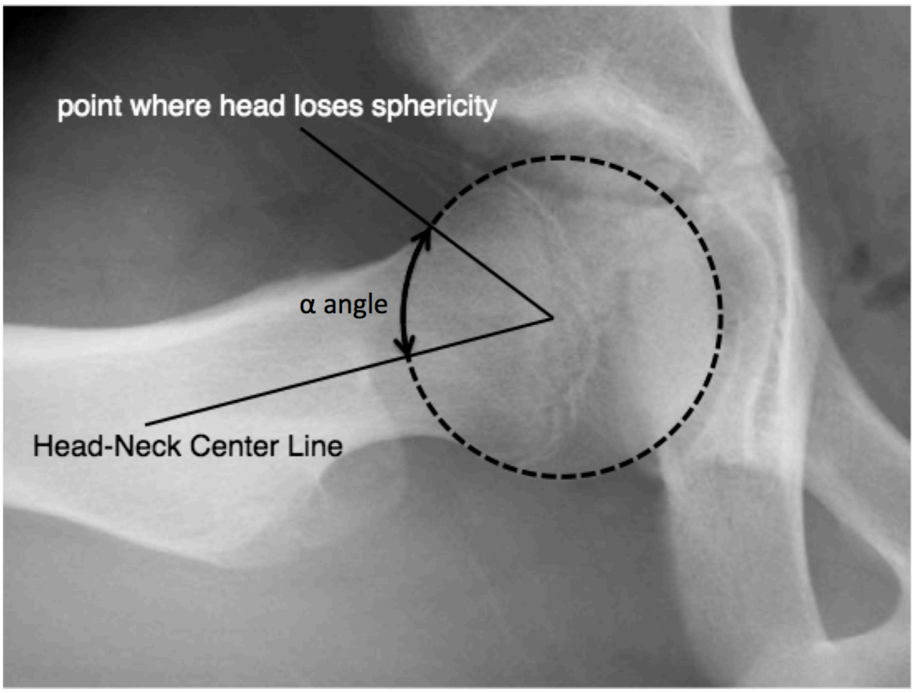
point where head loses sphericity
α angle
Head-Neck Center Line

Fig.2

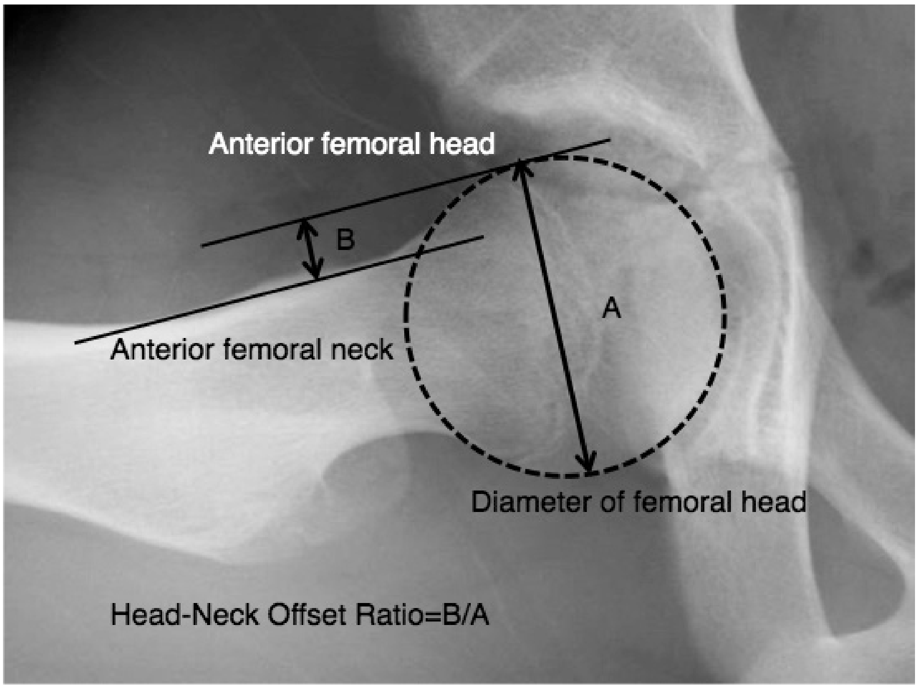
Anterior femoral head
B
A
Anterior femoral neck
Diameter of femoral head
Head-Neck Offset Ratio=B/A

Fig.3 (a),(b)

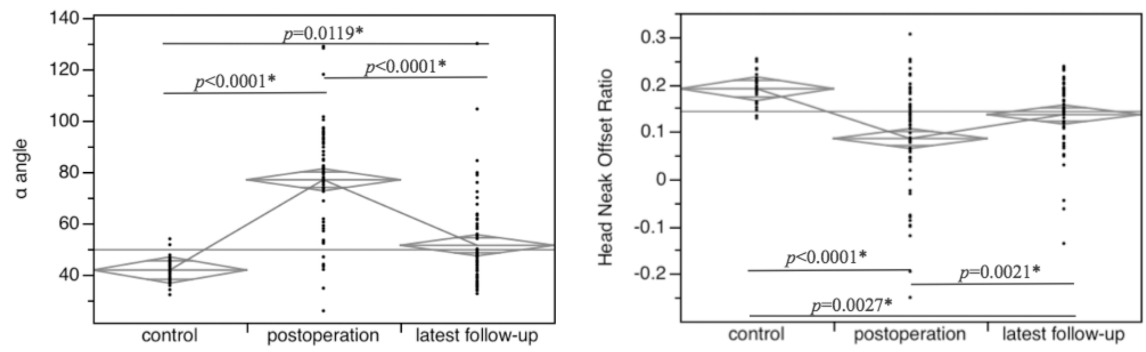

Fig.4 (a),(b)