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

Mio Akiyama · Yasuharu Nakashima · Toshio Kitano ·
Tomoyuki Nakamura · Kazuyuki Takamura ·
Yusuke Kohno · Takuaki Yamamoto · Goro Motomura ·
Masanobu Ohishi · Satoshi Hamai · Yukihide Iwamoto

Received: 14 June 2013 / Accepted: 18 July 2013 / Published online: 11 September 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract

Purpose We examined the remodelling of the femoral head–neck junction in patients with slipped capital femoral epiphysis (SCFE) and the frequency of residual cam deformities.

Methods We reviewed 69 hips in 56 patients with stable SCFE who had undergone in situ pinning. Mean age at slip was 11.7 years and the follow-up period 63.4 months. Cam deformity was evaluated using the anterior offset alpha (α) angle and head–neck offset ratio (HNOR).

Results The average α angle and HNOR significantly improved from 76.2° to 51.3° and 0.086 to 0.135, respectively; 25 hips (36.2 %) still had an α angle greater than 50°, and 32 hips (46.4 %) had an HNOR of under 0.145. A multivariate analysis selected age at onset and slip angle as risk factors for cam deformity, with cutoff values 11.1 years and 21.0°, respectively.

Conclusions Although most hips had remodelling of the head–neck junction, 29.4 % had residual cam deformities that may be susceptible to femoroacetabular impingement.

Introduction

Slipped capital femoral epiphysis (SCFE) is a common hip disorder in adolescents. The capital femoral epiphysis displaces posteroinferiorly 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 widely accepted treatment for a mild to moderate slip is pinning with one or two screws/pins under fluoroscopic imaging with no attempt at reduction of the slip: so-called in situ pinning. Successful clinical results have been reported with in situ pinning [1, 2] showing that in most hips remodelling of the deformed femoral head–neck junction was achieved and returned to normal range of hip motion. However, some patients failed to attain such remodelling and showed premature osteoarthritis (OA) of the hip.

Jones et al. [3] classified SCFE remodelling 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 head and neck are at the same level; in type C, the head is posterior to the neck, and there is prominence in the mid region of the neck. They defined types A and B as being completely remodelled and type C as failure. This classification system has been widely used to assess remodelling in SCFE.

There is growing interest in the concept of femoroacetabular impingement (FAI) as an aetiological factor for the development of OA of the hip [4–7]. Continuous impingements are thought to cause groin pain with flexion and eventually lead to labral and cartilage degeneration. 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 the Drehmann sign, which is

M. Akiyama · Y. Nakashima (✉) · Y. Kohno · T. Yamamoto ·
G. Motomura · M. Ohishi · S. Hamai · Y. Iwamoto
Department of Orthopaedic Surgery, Graduate School of Medical
Science, Kyushu University, Fukuoka, Japan
e-mail: yasunaka@ortho.med.kyushu-u.ac.jp

T. Kitano
Department of Pediatric Orthopaedic Surgery, Osaka City General
Hospital, Osaka, Japan

T. Nakamura · K. Takamura
Department of Orthopaedic Surgery, Fukuoka Children's Hospital,
Fukuoka, Japan

used clinically to evaluate the existence of FAI[8]. Therefore, there is a need to re-evaluate remodelling in SCFE by taking FAI into consideration. We conducted this study to examine the remodelling of the femoral head–neck junction and the frequency of cam deformity in patients with SCFE after skeletal maturity.

Methods

Patients This multicentre retrospective study was approved by our institutional review board. We analysed patients with SCFE treated by in situ pinning in the Kyushu University Hospital, Osaka Medical Centre, 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 under 24 months and an incomplete set of radiographs. A total of 69 hips in 56 patients (41 boys and 15 girls) were included in this study. Mean age at pinning was 11 years and eight months. All patients were followed up at least until skeletal maturity. Mean follow-up was 5.28 years (range 24–368 months). Bilateral hip joint involvement was present in 13 patients. Forty-two hips in 42 age-matched cases were used as normal controls. These cases were diagnosed as transient arthritis of the hip, and the contralateral hips were used. 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-up.

Radiographic measurements 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]. PSA is the angle between the line along the plane of the physis and the line perpendicular to the femoral neck axis. To assess cam deformity, two measurements were performed: the anterior offset alpha (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 is drawn connecting the centre of the femoral head and the centre of femoral neck. A second line is drawn from the centre of the femoral head to a point on the anterolateral head–neck junction where the radius of the 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). Intersection of these two lines form α angle; an α angle greater than 50° is suggestive of cam deformity [12]. The head–neck offset ratio, described by Eijer et al. [13], is also a measure of cam deformity (Fig. 2).

Fig. 1 Lateral radiograph of a hip illustrating the method of Notzli et al. [11] for assessing the anterior offset alpha (α) angle. A line was drawn connecting the centre of femoral head and the centre of femoral neck. A second line is drawn from the centre of femoral head to a point on the anterolateral head–neck junction. The intersection of these two lines forms the α angle

Profiles of the anterior head and neck were quantified by head–neck ratio measurements. In brief, three parallel lines are drawn, with line 1 drawn through the centre 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 the femoral head. In the original description by Eijer et al. [13], the mean HNOR was 0.21 [standard deviation (SD) 0.03 (0.14–0.25)], suggesting a reference interval lower limit of 0.145. We also measured Wiberg's centre-edge (CE) angle, Sharp angle, and presence of the crossover sign on 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 (MA and YK) in a blinded manner during two reviewing sessions held one month apart.

Fig. 2 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 the femoral head

Statistical analysis Chi-square and Wilcoxon rank-sum tests were used to compare clinical and radiographic parameters between 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. Parameters included in the initial backwards stepwise regression were PSA, age at pinning, BMI, CE angle, sharp angle and the crossover sign. The significance for including a variable in the model was $p=0.20$ and for removing 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 $AUC \geq 0.650$. Intraobserver and interobserver reliabilities were evaluated using kappa statistics. Confidence intervals (CIs) of 95 % were calculated for kappa values. Kappa values 0.4–0.6 indicate moderate agreement, 0.6–0.8 good agreement and >0.8 excellent agreement.

Results

Average α angle and HNOR at pinning were $76.2 \pm 21.1^\circ$ and 0.086 ± 0.109 , respectively. These measurements significantly improved to $51.3 \pm 17.2^\circ$ and 0.135 ± 0.069 at the latest follow-up, respectively ($p=0.0003$ and $p=0.0075$, respectively). However, the α angle remained significantly larger compared with controls ($41.8 \pm 4.47^\circ$, $p=0.0475$) (Fig. 3). At pinning, 55 hips (86.2 %) had an α angle greater than 50° ; 25 hips (36.2 %) still had α angle of under 50° at the latest follow-up. A similar tendency was observed in terms of HNOR: 46 and 32 hips, respectively, had HNOR of under 0.145 at pinning and at the latest follow-up. Forty-three (62.3 %) and 20 (29.4 %) hips were within criteria of cam deformity (α angle

over 50° and HNOR under 0.145) at pinning and at the latest follow-up, respectively (Table 1).

Among 69 hips, 60 were classified as Jones type A, eight as type B, and one as type C. The number of hips with an α angle over 50° was 18 (30 %) in type A, six (75 %) in type B and one (100 %) in type C. The number of hips with HNOR under 0.145 was 24 (40 %) in type A, seven (87.5 %) in type B and one (100 %) in type C, indicating a large number of hips in type A and B still showing cam deformity (Table 1).

We compared parameters between hips with and without cam deformity in the SCFE group (Table 2). Age at pinning was significantly older in hips with than in those without cam deformity (12.6 ± 1.37 vs. 11.4 ± 1.78 years; $p=0.0225$). Hips with cam deformity had a significantly larger preoperative PSA versus those without ($42.2 \pm 18.05^\circ$ vs $28.3 \pm 13.6^\circ$; $p=0.0035$).

Parameters included in the initial backwards stepwise regression were age at pinning, sex, BMI, PSA, CE angle, sharp angle and presence of a crossover 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 preoperative PSA ($p=0.0004$) were significant and independent risk factors (Table 3). Older age at operation and greater PSA resulted in higher prevalence of cam deformities. Age cutoff value at pinning was 11 years and one month; AUC was 0.70653, indicating good accuracy. Slip-angle cutoff value was 21.0° ; AUC was 0.84272, indicating excellent accuracy (Fig. 4).

Intraobserver measurement reliability, evaluated with the use of the intraclass correlation coefficient, was excellent (range, 0.8045–0.9512). Interobserver measurement reliability was good (range, 0.6337–0.9391).

Discussion

Remodelling of the femoral head–neck junction was re-evaluated in terms of the development of cam deformity in this

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

Table 1 Radiological parameters

	Parameters	Preoperative	Postoperative	Latest follow-up	Control
Total includes both the alpha angle >50° and HNOR <0.145. Values are mean (standard deviation) <i>PSA</i> posterior slip angle, <i>α angle</i> anterior offset alpha angle, <i>HNOR</i> head–neck offset ratio, <i>CE</i> angle centre–edge angle, <i>SCFE</i> slipped capital femoral epiphysis	Radiological parameters				
	PSA (°)	23.2 (17.1)			
	α angle (°)		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 (°)			28.1 (6.67)	23.7 (7.62)
	Sharp angle (°)			41.5 (3.53)	48.5 (3.57)
	Jones classification				
	Type A (<i>n</i> , %)		37 hips 53.6 %	60 hips 86.9 %	42 hips 100 %
	Type B (<i>n</i> , %)		19 hips 27.5 %	8 hips 11.7 %	0 hip 0 %
	Type C (<i>n</i> , %)		13 hips 18.8 %	1 hip 1.44 %	0 hip 0 %
	Prevalence of cam deformity in SCFE				
	α angle >50° (<i>n</i> , %)		55 hips 86.2 %	25 hips 36.2 %	2 hips 4.7 %
	HNOR <0.145 (<i>n</i> , %)		46 hips 71.9 %	32 hips 46.4 %	3 hips 7.1 %
	Total (α angle >60° and HNOR <0.145) (<i>n</i> , %)		43 hips 62.3 %	20 hips 29.4 %	1 hip 2.4 %
	Prevalence of cam deformity in each Jones class at the latest follow-up		α angle >50°	HNOR <0.145	Total
	Type A (<i>n</i> , %)		18 hips 30.0 %	24 hips 40.0 %	13 hips 22.0 %
	Type B (<i>n</i> , %)		6 hips 75.0 %	7 hips 87.5 %	6 hips 85.7 %
	Type C (<i>n</i> , %)		1 hip 100.0 %	1 hip 100.0 %	1 hip 100.0 %

multicentre study. We showed that α angle and HNOR improved from 76.2° and 0.086 to 51.3° and 0.135, respectively, at the latest follow-up. However, 29.4 % of hips still met criteria for cam deformity at skeletal maturity. We also determined the risk factors for cam deformity as being preoperative PSA and age at pinning. Risks for cam deformity include a SCFE diagnosed at over 11.1 years and a slipped SCFE of over 21.0°.

The current standard treatment for mild to moderate SCFE is in situ pinning, with stabilisation of the slip and premature physal closure being the primary goals. Pinning without correction was based on the expectation of bone remodelling. Jones et al. reported that clinically significant remodelling occurred in 90 % of patients with mild slips and 50 % with moderate slips. Only 11 % of hips were classified as poor remodelling (type

C). Dawes et al. reviewed 59 SCFEs at a mean 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, respectively, within the normal range. Other studies also showed good bone remodelling after mild and moderate slips [15, 16]. In relation to the longer follow-up, however, Bellemans et al. showed 10 % of hips had poor function due to residual deformity at the anterior femoral head–neck junction in a study averaging 11.4 years of follow-up [17]. Westhoff et al. reported ROM of the hip was smaller on the slip side and

Table 2 Comparison between 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/m ²)	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 (°)	42.2 (18.05)	28.3 (13.6)	8.55	0.0035*
CE angle (°)	26.4 (6.87)	28.7 (6.50)	1.4711	0.2252
Crossover sign (<i>n</i> , %)	13 hips 61.9 %	26 hips 54.2 %	0.356	0.5508

*Statistical significance

Table 3 Predictors for cam deformity using multiple logistic 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

that patients showed totally less positive mechanical ability even after growth arrest [18].

The concept of FAI helps to explain the development of premature OA in patients with 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 adults. In a study on patients undergoing hip resurfacing arthroplasty, Beaulé et al. found that over 50 % of patients with end-stage OA had insufficient head–neck offset 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 results show improvement in head–neck offset by remodelling, 29.4 % of SCFE remained within the criteria of cam deformity. Even in hips within the Jones types A and B criteria, considered to be good remodelling, 22.0 % and 85.7 % of 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. Age at pinning and slip severity significantly influenced the rate of cam deformity.

With the ROC analysis, we found that cam deformities tend to appear in children over 11.1 years and in hips that have slipped more than 21.0° . 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 adapting corrective osteotomies in cases of poor remodelling. Additionally, Kandzierski et al. reported that a growth plate finally reaches a shape of a convex meniscus and that minor ruggedness of its surface gradually disappears at the age of 11–13 years [22]. These growth-plate changes might indicate poor remodelling ability after the age of 11 years.

This study had several limitations. As a retrospective evaluation of database and images, this study lacks correlation with images and clinical data. A prolonged follow-up period was needed to elucidate the effects of remodelling on clinical outcomes. Additionally, the normal α angle range is controversial; α angle was originally described based on magnetic resonance imaging (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 over 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 cam deformity criteria using α angle and outside 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. Head–neck offset ratio may be less sensitive to these secondary changes. Considering these factors, we recommend that α angle and HNOR be used in conjunction.

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

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

References

1. Boyer DW, Mickelson MR, Ponseti IV (1981) Slipped capital femoral epiphysis. long-term follow-up study of one hundred and twenty-one patients. *J Bone Joint Surg Am* 1:85–95
2. Carney BT, Weinstein SL, Noble J (1991) Long-term follow-up of slipped capital femoral epiphysis. *J Bone Joint Surg Am* 5:667–674
3. Jones JR, Paterson DC, Hillier TM, Foster BK (1990) Remodelling after pinning for slipped capital femoral epiphysis. *J Bone Joint Surg Br* 4:568–573
4. Ganz R, Parvizi J, Beck M, Leunig M, Notzli H, Siebenrock KA (2003) Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 417:112–120
5. Leunig M, Casillas MM, Hamlet M, Hersche O, Notzli H, Slongo T, Ganz R (2000) Slipped capital femoral epiphysis: early mechanical damage to the acetabular cartilage by a prominent femoral metaphysis. *Acta Orthop Scand* 4:370–375
6. Goodman DA, Feighan JE, Smith AD, Latimer B, Buly RL, Cooperman DR (1997) Subclinical slipped capital femoral epiphysis. Relationship to osteoarthritis of the hip. *J Bone Joint Surg Am* 10:1489–1497
7. Rab GT (1999) The geometry of slipped capital femoral epiphysis: Implications for movement, impingement, and corrective osteotomy. *J Pediatr Orthop* 4:419–424
8. Kamegaya M, Saisu T, Nakamura J, Murakami R, Segawa Y, Wakou M (2011) Drehmann sign and femoro-acetabular impingement in SCFE. *J Pediatr Orthop* 8:853–857
9. Loder RT, Richards BS, Shapiro PS, Reznick LR, Aronson DD (1993) Acute slipped capital femoral epiphysis: the importance of physeal stability. *J Bone Joint Surg Am* 8:1134–1140
10. Barrios C, Blasco MA, Blasco MC, Gasco J (2005) Posterior sloping angle of the capital femoral physis: a predictor of bilaterality in slipped capital femoral epiphysis. *J Pediatr Orthop* 4:445–449
11. Notzli HP, Wyss TF, Stoecklin CH, Schmid MR, Treiber K, Hodler J (2002) The contour of the femoral head–neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br* 4:556–560
12. Pollard TC, Villar RN, Norton MR, Fern ED, Williams MR, Simpson DJ, Murray DW, Carr AJ (2010) Femoroacetabular impingement and classification of the cam deformity: the reference interval in normal hips. *Acta Orthop* 1:134–141
13. Eijer H, Myers SR, Ganz R (2001) Anterior femoroacetabular impingement after femoral neck fractures. *J Orthop Trauma* 7:475–481
14. Dawes B, Jaremko JL, Balakumar J (2011) Radiographic assessment of bone remodelling in slipped upper femoral epiphyses using Klein's line and the alpha angle of femoral-acetabular impingement: a retrospective review. *J Pediatr Orthop* 2:153–158
15. Dobbs MB, Weinstein SL (2001) Natural history and long-term outcomes of slipped capital femoral epiphysis. *Instr Course Lect* 50:571–575
16. DeLullo JA, Thomas E, Cooney TE, McConnell SJ, Sanders JO (2007) Femoral remodeling may influence patient outcomes in slipped capital femoral epiphysis. *Clin Orthop Relat Res* 457:163–170
17. Bellemans J, Fabry G, Molenaers G, Lammens J, Moens P (1996) Slipped capital femoral epiphysis: a long-term follow-up, with special emphasis on the capacities for remodeling. *J Pediatr Orthop B* 3:151–157
18. Westhoff B, Ruhe K, Weimann-Stahlschmidt K, Zilkens C, Willers R, Krauspe R (2012) The gait function of slipped capital femoral epiphysis in patients after growth arrest and its correlation with the clinical outcome. *Int Orthop* 36(5):1031–1038
19. Beaulé PE, Harvey N, Zaragoza E, Le Duff MJ, Dorey FJ (2007) The femoral head/neck offset and hip resurfacing. *J Bone Joint Surg Br* 1:9–15
20. Murray RO (1965) The aetiology of primary osteoarthritis of the hip. *Br J Radiol* 455:810–824
21. Zilkens C, Bittersohl B, Jäger M, Miese F, Schultz J, Kircher J, Westhoff B, Krauspe R (2011) Significance of clinical and radiographic findings in young adults after slipped capital femoral epiphysis. *Int Orthop* 35(9):1295–1301
22. Kandzierski G, Matuszewski L, Wójcik A (2012) Shape of growth plate of proximal femur in children and its significance in the aetiology of slipped capital femoral epiphysis. *Int Orthop* 36(12):2513–2520
23. Clohisy JC, Carlisle JC, Beaulé PE, Kim YJ, Trousdale RT, Sierra RJ, Leunig M, Schoenecker PL, Millis MB (2008) A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am* 90(4):47–66